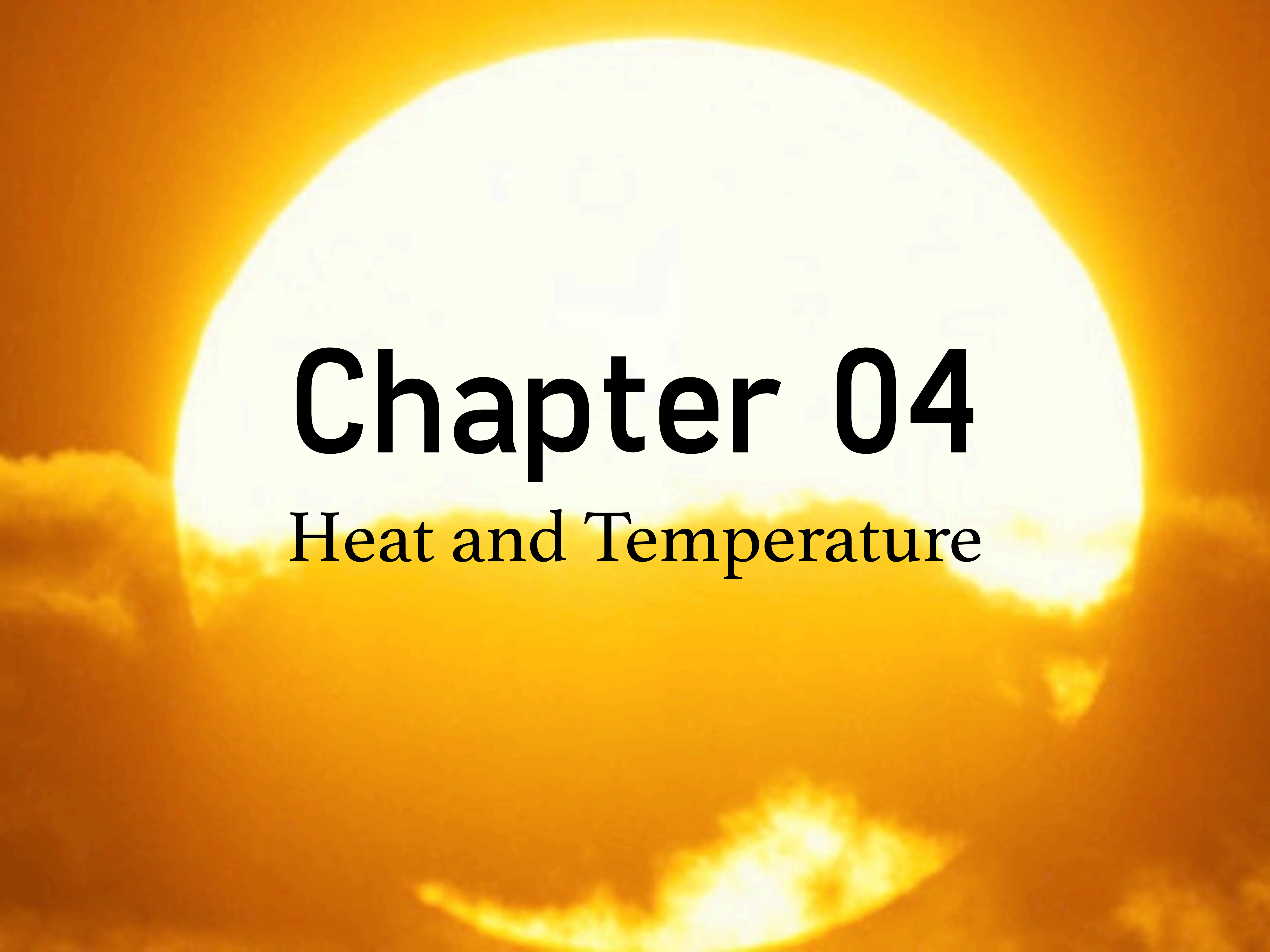


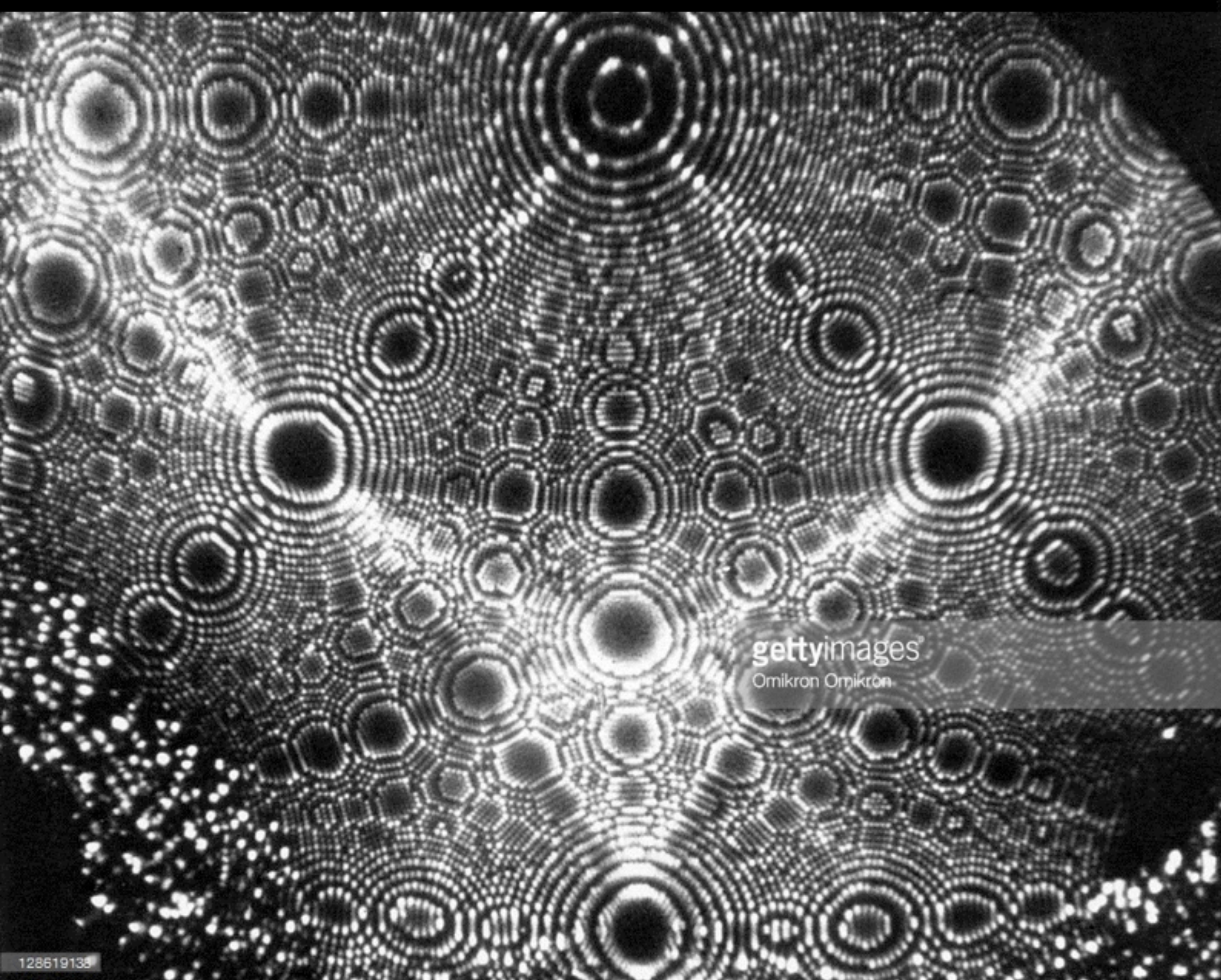
Chapter 04

Heat and Temperature

Joule Proves Heat = Energy

- Such a clever experiment, he got the unit named after him!
- Drop a weight through a known distance: easy conversion of PE to KE
- Use the KE to spin a paddle in water, and watch the temperature rise

Section 4.1

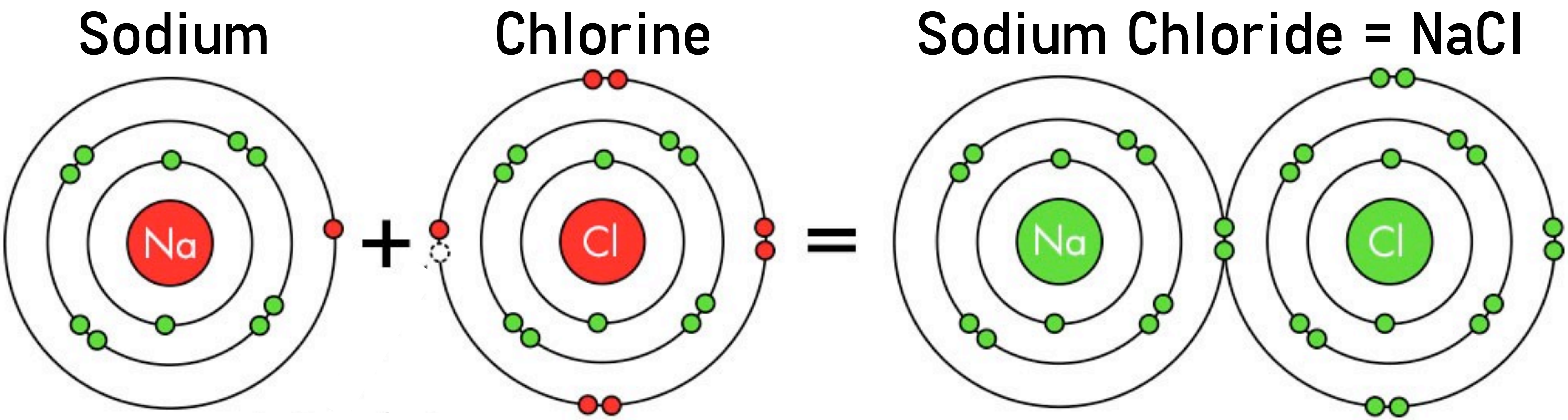


The Kinetic Molecular Theory

Aristotle: Wrong Again!

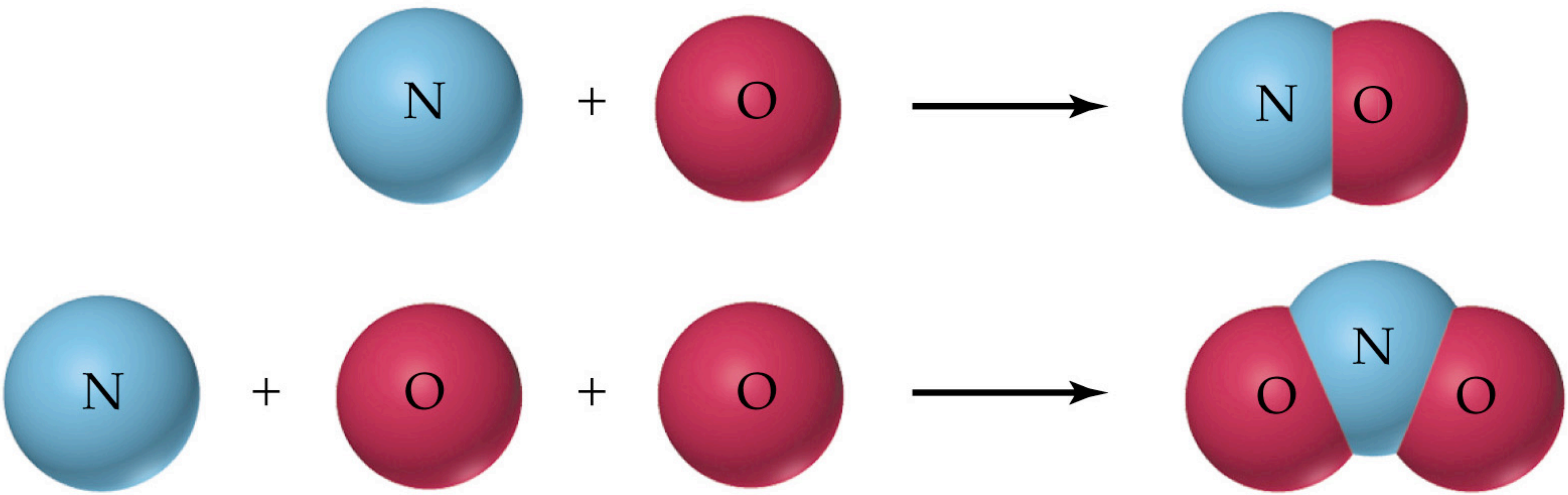
- So, this guy called Democritus suggests that matter is made of tiny, tiny indivisible particles. He called them atoms
- Aristotle says no: earth, air, fire, water, duh!
- Newton was thinking about this, but couldn't formalize
- As chemistry develops, strong indirect evidence of atoms/molecules

Molecules



- An atom is a single unit: sodium (Na), maybe chlorine (Cl)
- A molecule sticks several atoms together: NaCl = one sodium stuck to one chlorine = table salt
- For purposes of kinetic theory, molecule = smallest unit, either molecule or elemental atom

True or False:

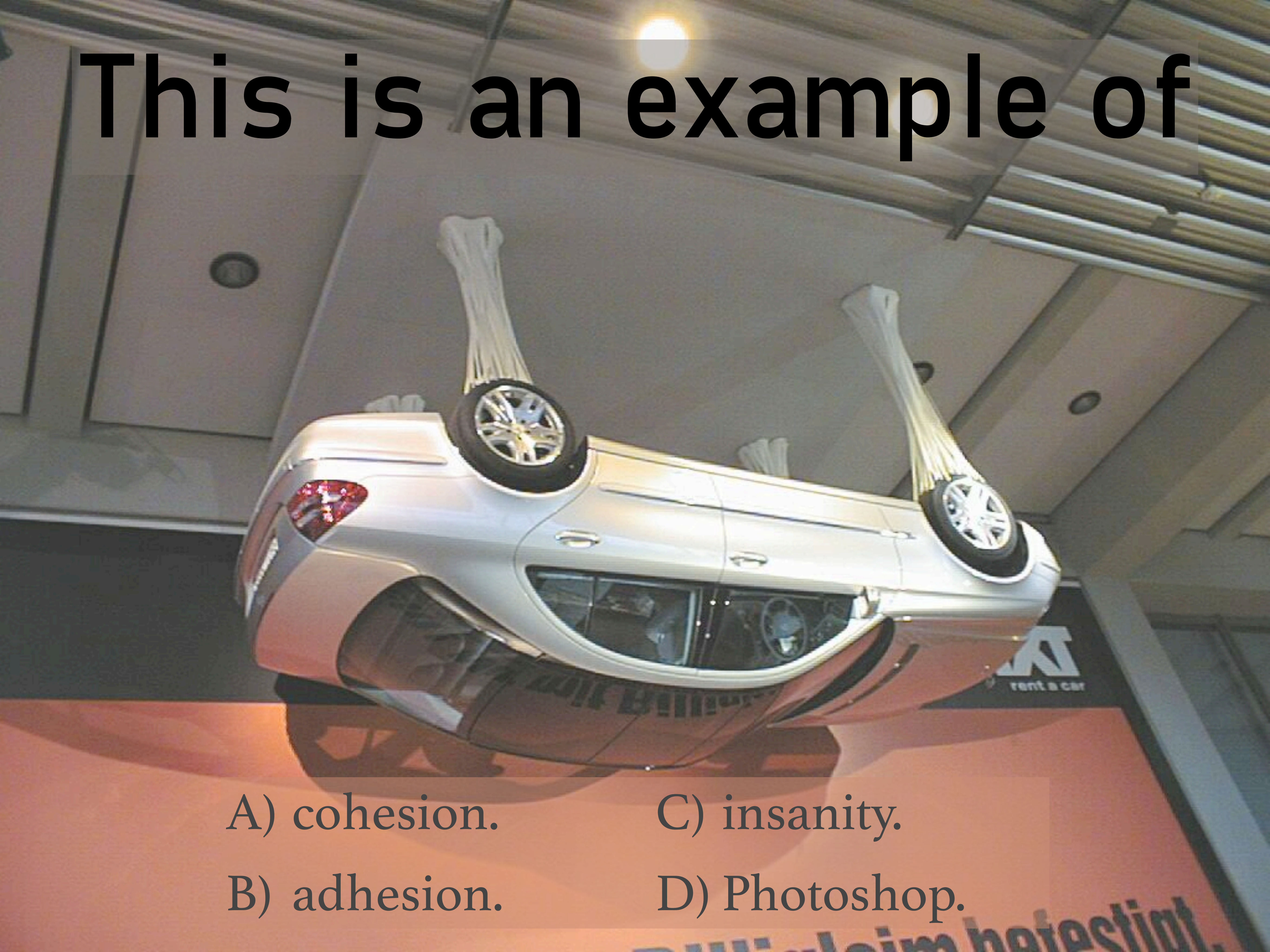


For the purpose of discussion, we can call both singular atoms and molecules composed of multiple atoms "molecules."

Molecules Interact

- Cohesion: stuff sticks to itself!
- Adhesion: stuff sticks to other stuff!

This is an example of



A) cohesion.

B) adhesion.

C) insanity.

D) Photoshop.


Phases
of Matter

Solids

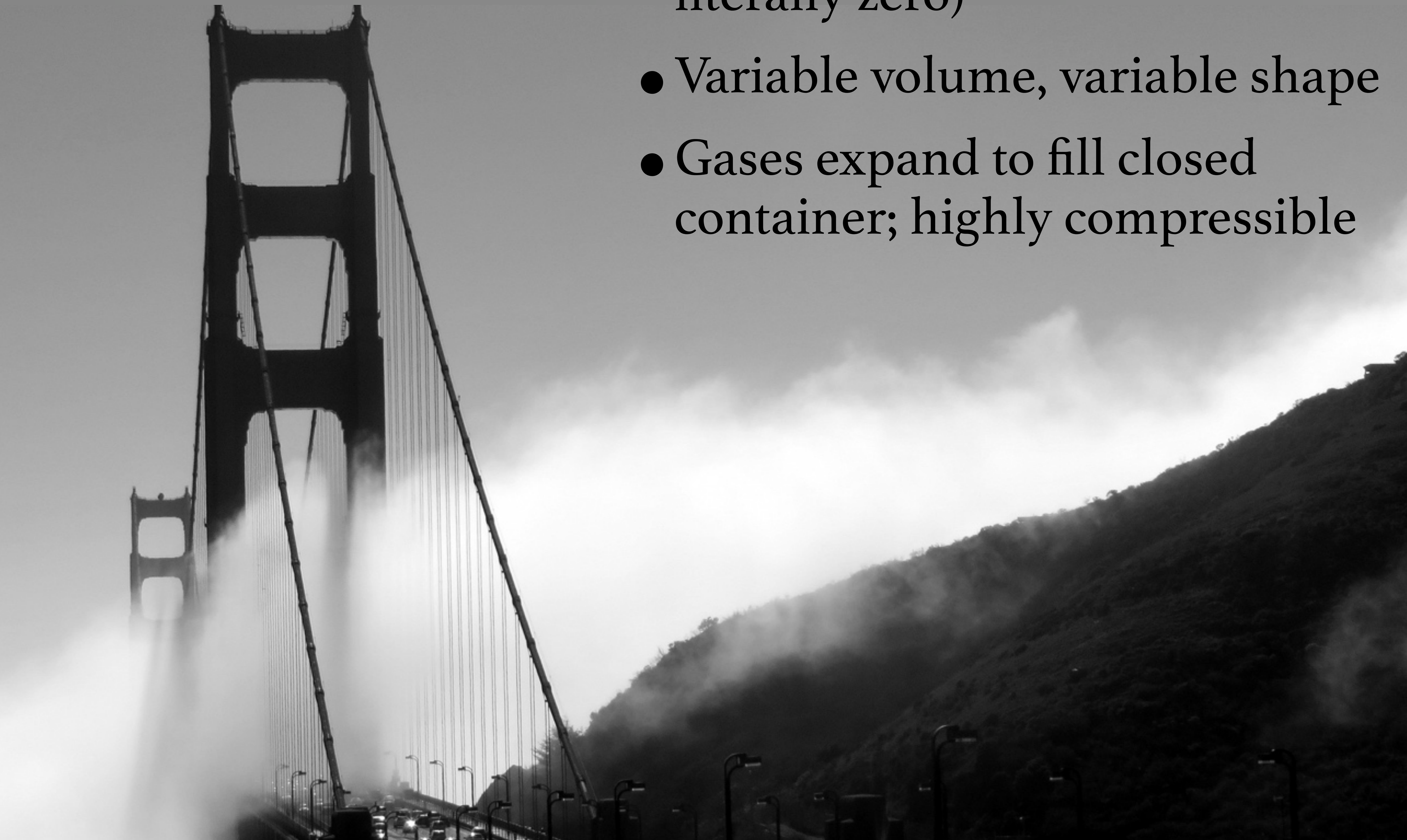
- Strong cohesive forces
- Fixed volume, fixed shape
- Solids do not flow

Liquids

- Less cohesion (but definitely not zero)
- Fixed volume, variable shape
- Liquids take the shape of their container; not compressible

Gases

- Extremely weak cohesion (practically zero, sometimes literally zero)
- Variable volume, variable shape
- Gases expand to fill closed container; highly compressible



Fluids?

A) Solids only.

B) Liquids only.

C) Gases only.

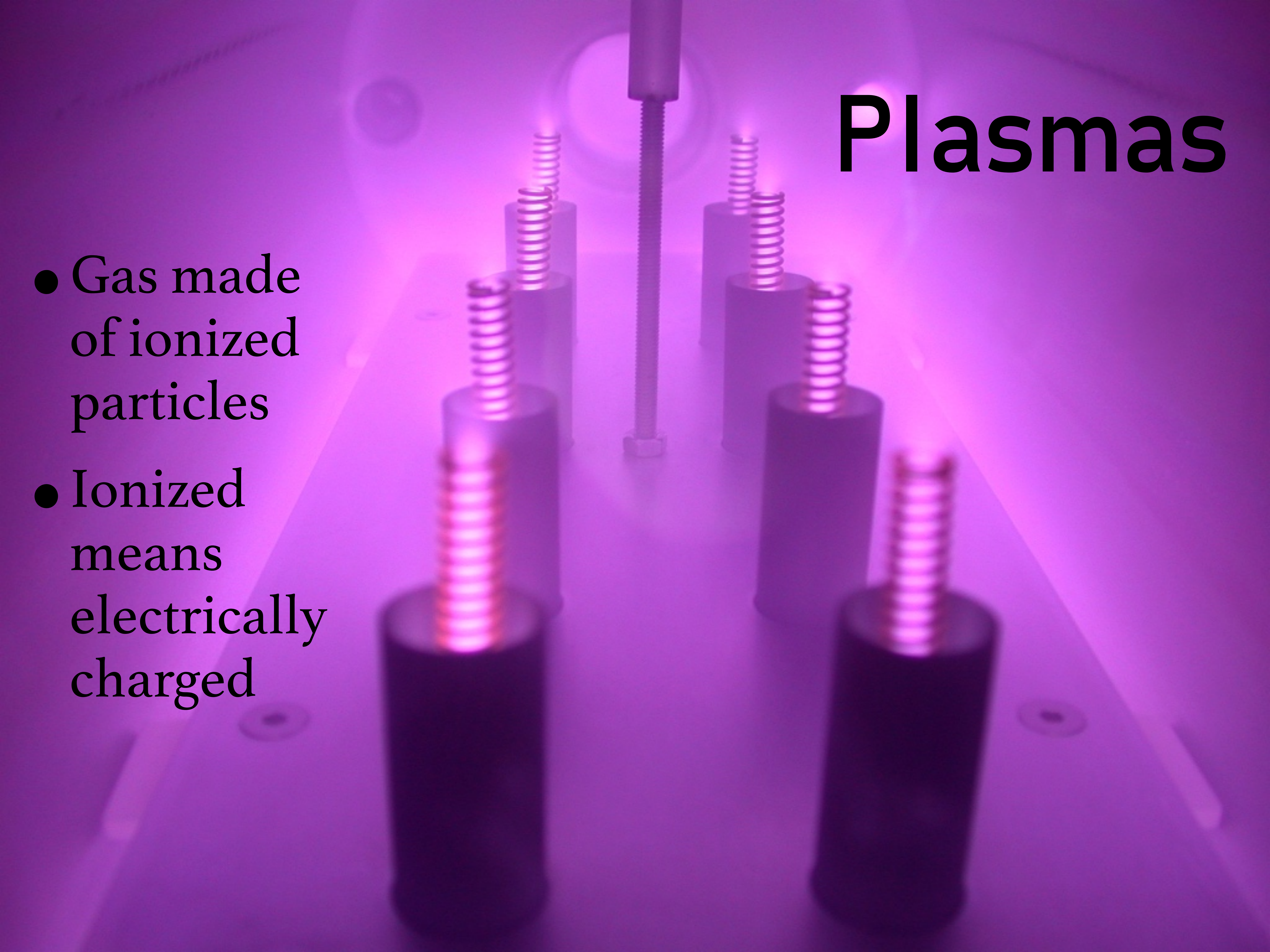
D) Solids & liquids.

E) Liquids & gases.

F) Gases & solids.

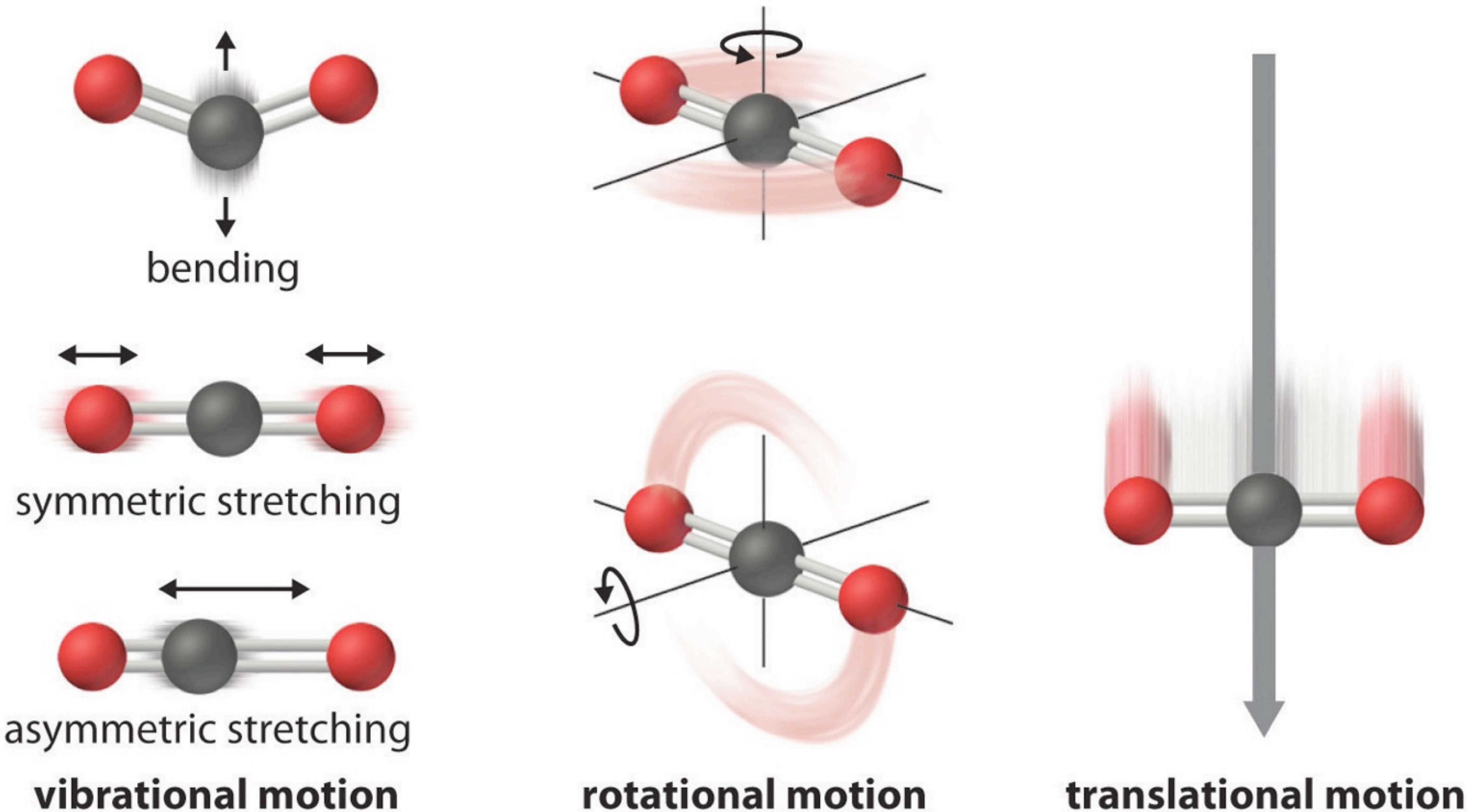
Plasmas

- Gas made of ionized particles
- Ionized means electrically charged



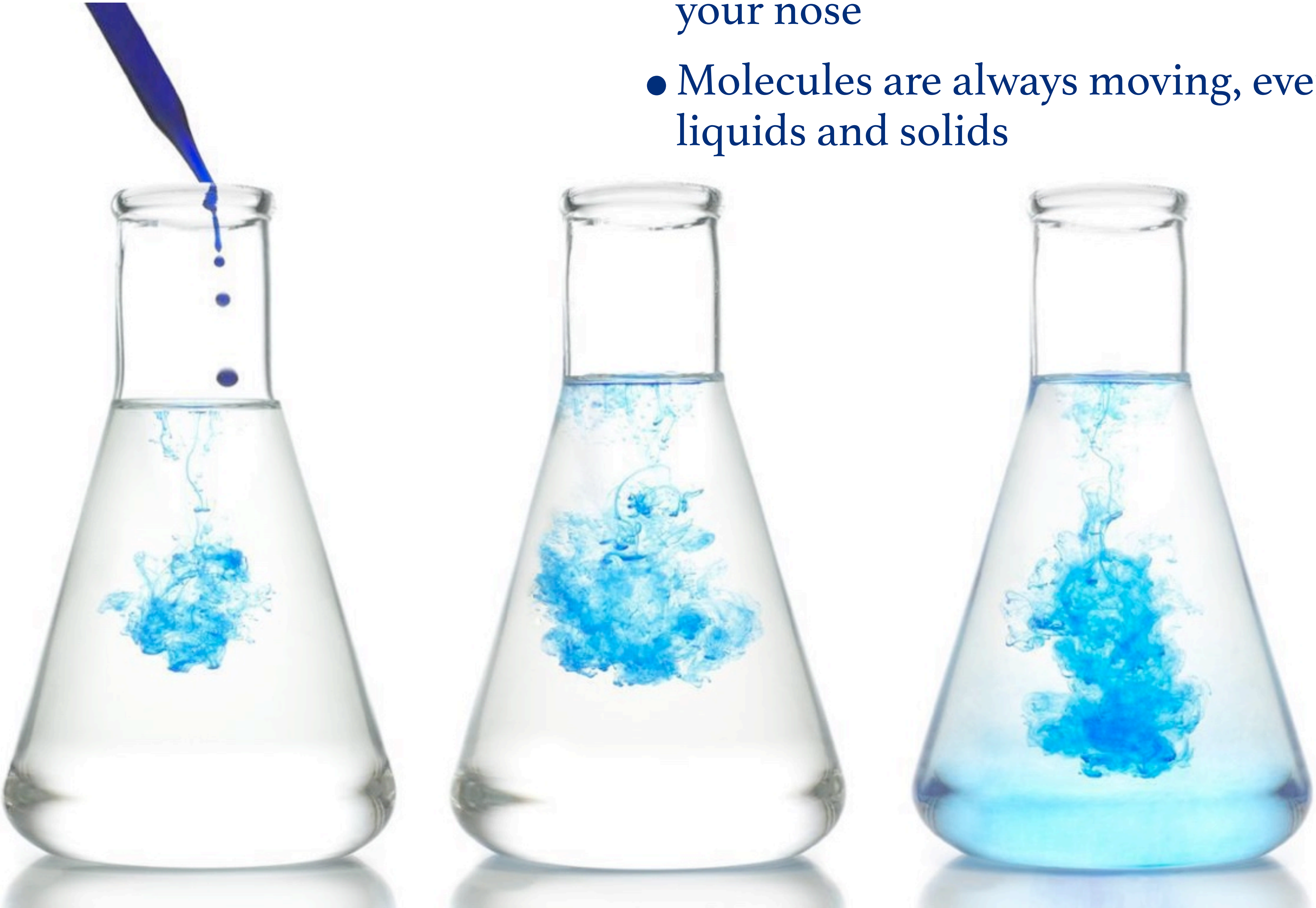
True or False:

The molecules of a solid material are always in motion.

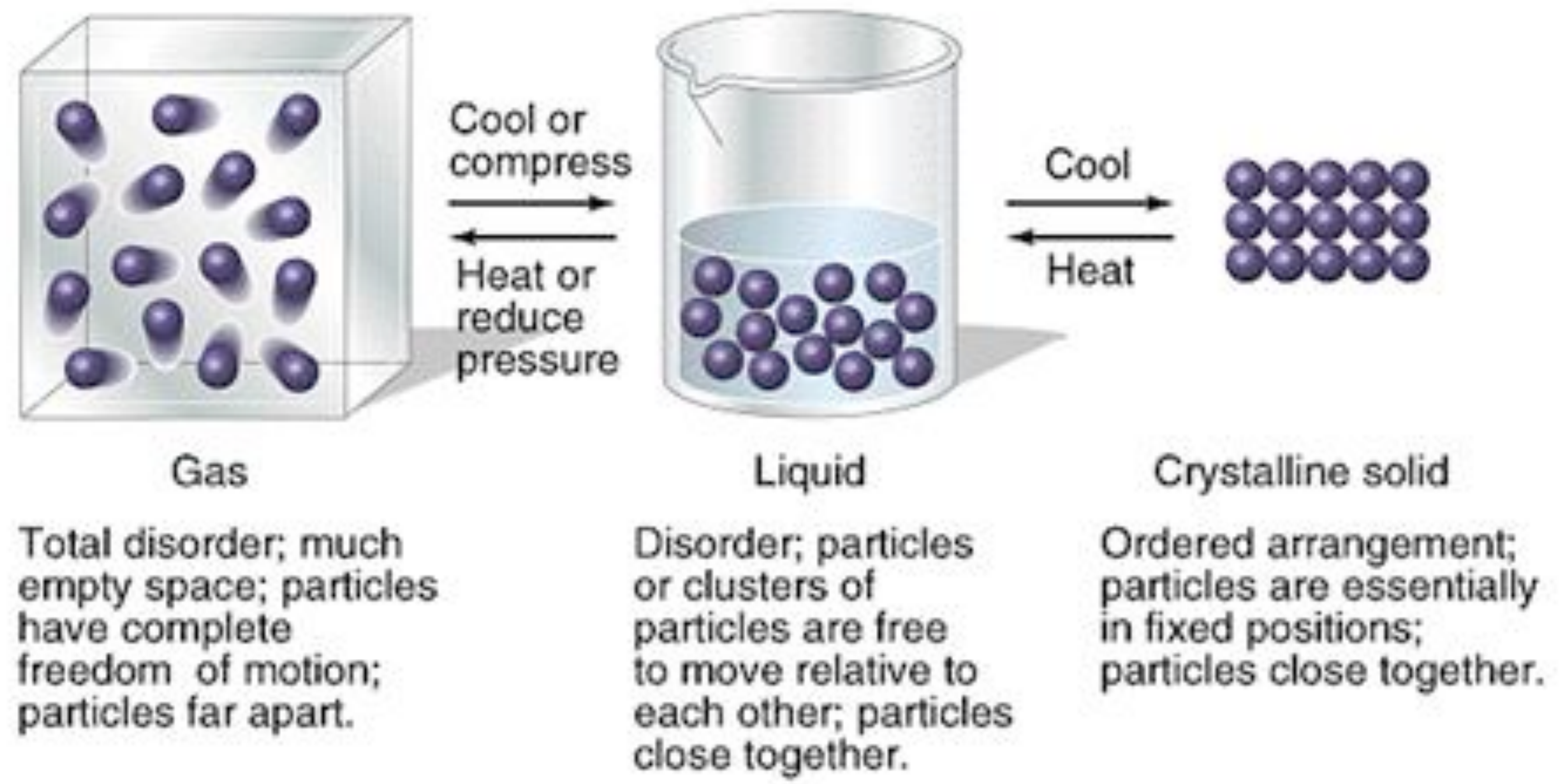


Molecules Move

- Diffusion: you don't have to be in the oven to smell the cookies baking!
- That smell means molecules moved through the air and got sucked in to your nose
- Molecules are always moving, even in liquids and solids

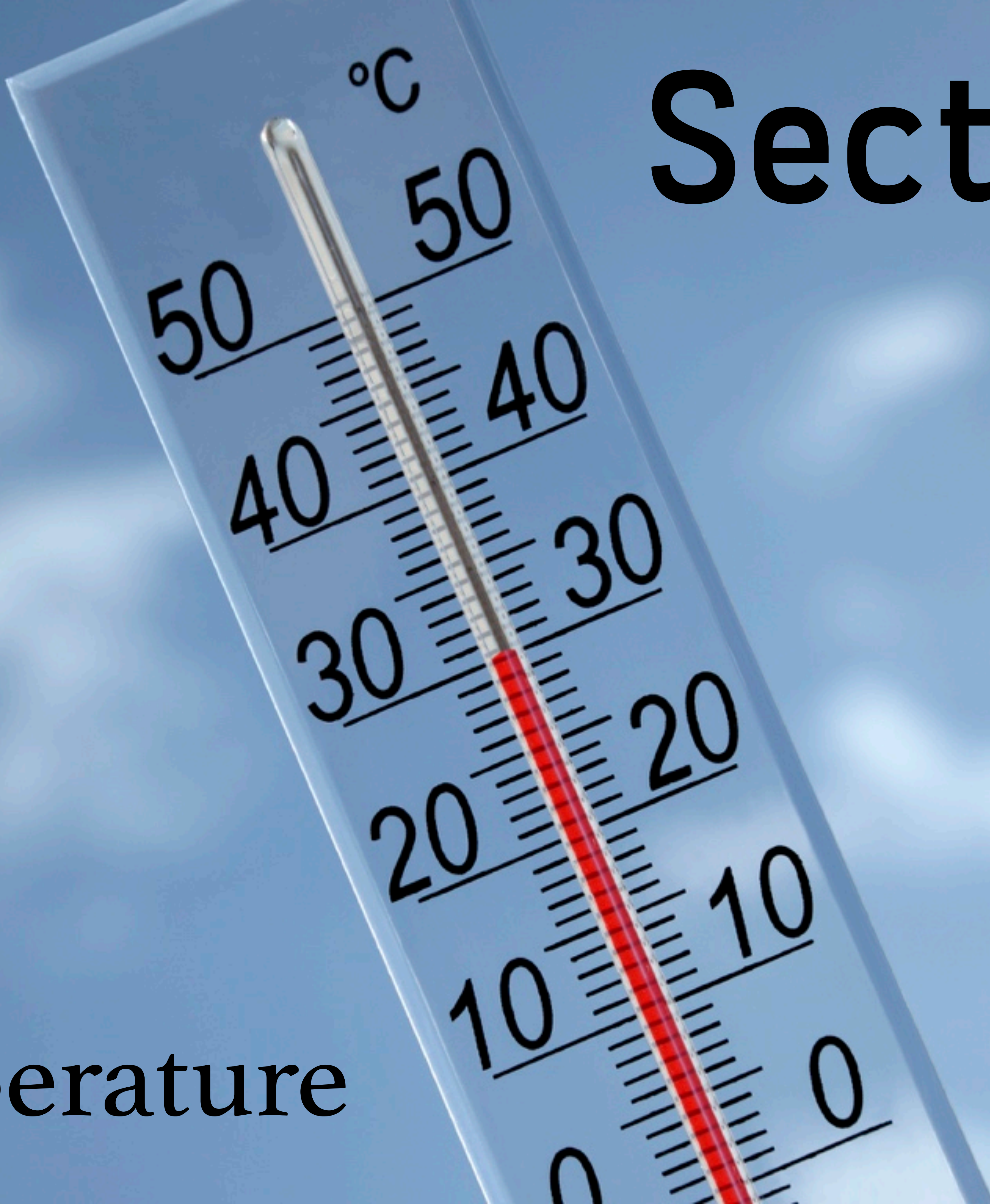


Kinetic Theory



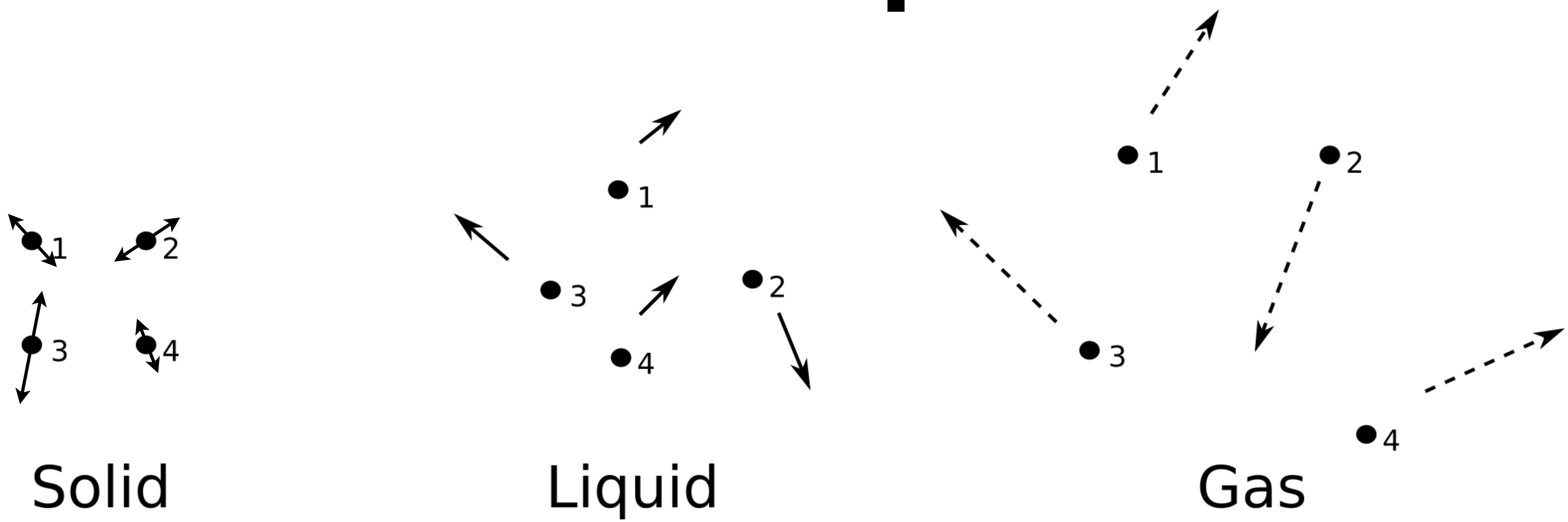
- Solid, liquid, gas, plasma: all molecules are moving–all the time
- Each and every molecule has kinetic energy (because it's moving!)
- Solids: slowest motion, least KE (gases/plasma have highest energy)

Section 4.2

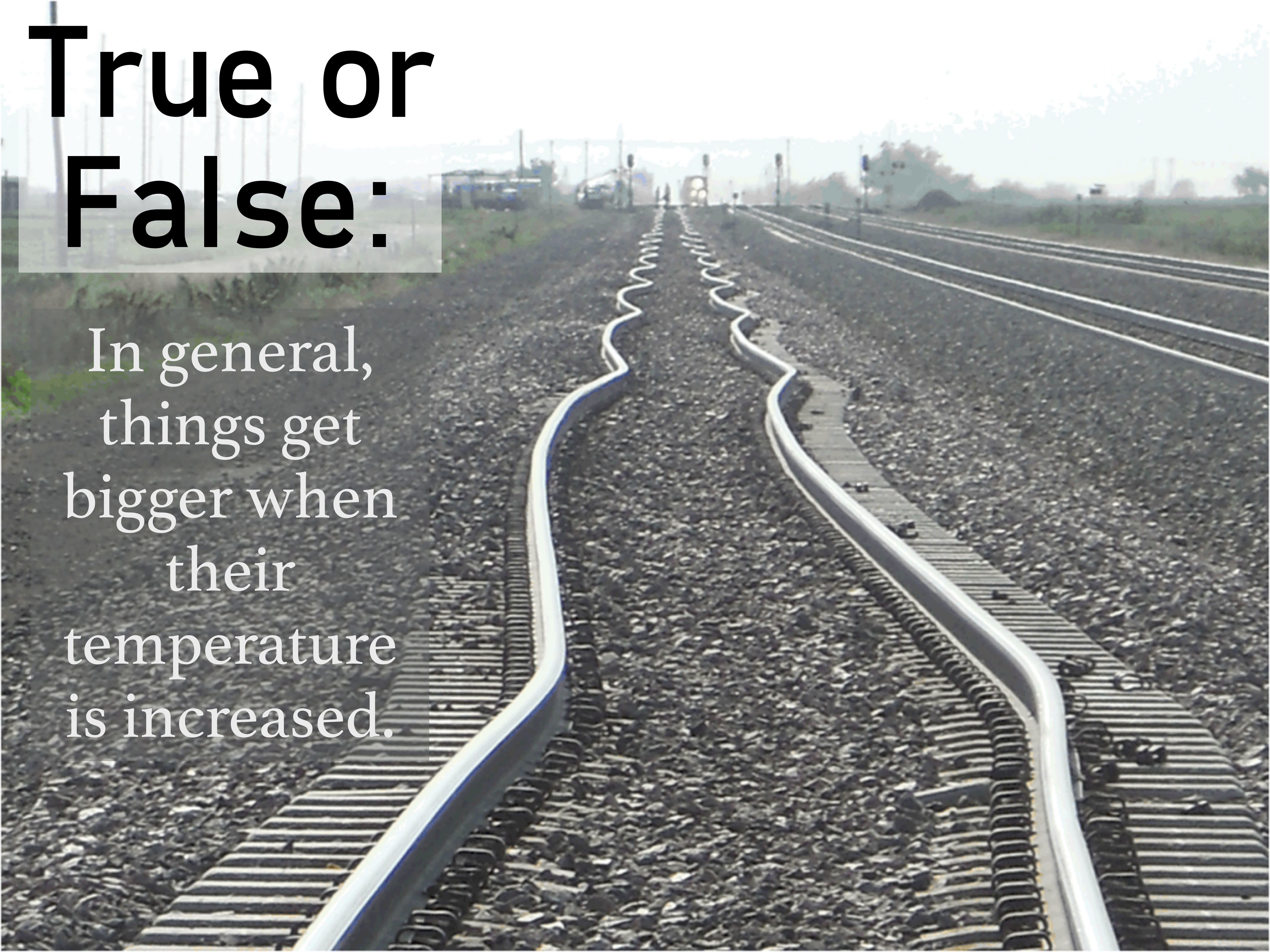


Temperature

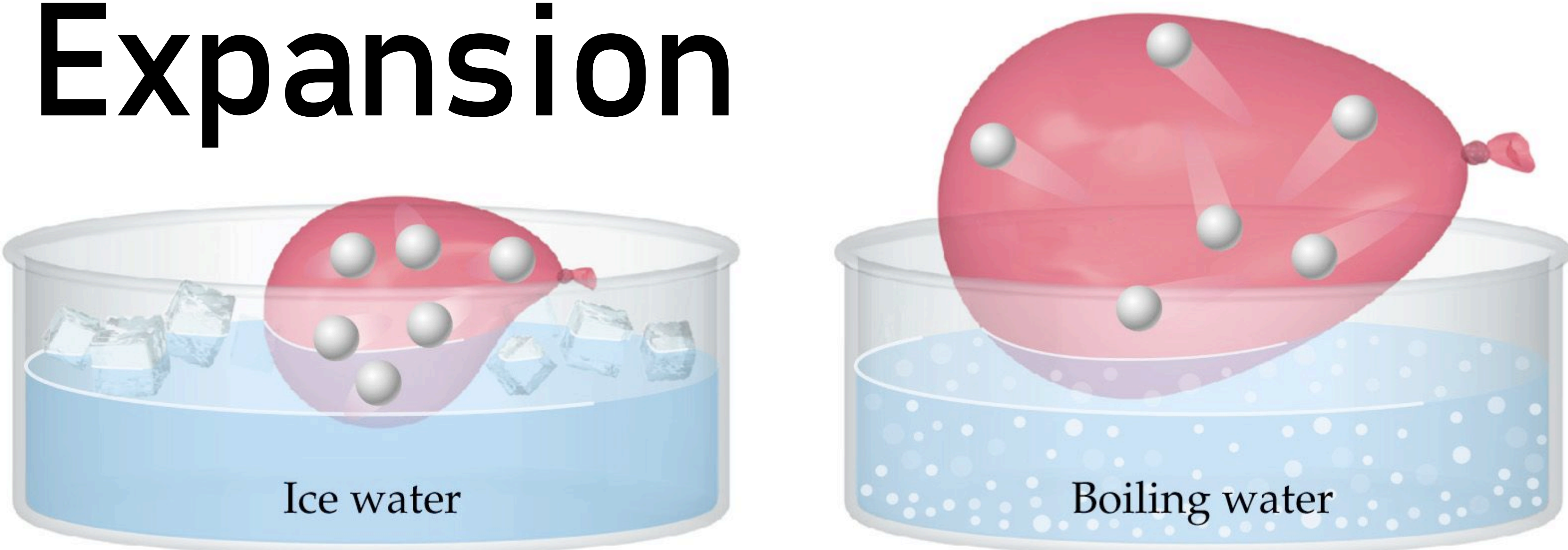
Define Temperature



- Average kinetic energy per molecule
- Has to be an average: not every molecule is doing exactly the same thing at exactly the same time!
- Increase temperature: increase speed of molecular motion (the molecules don't get more massive!)
- Decrease temperature: decrease speed (the molecules don't get less massive, either!)


True or False:
In general, things get bigger when their temperature is increased.

Thermal Expansion



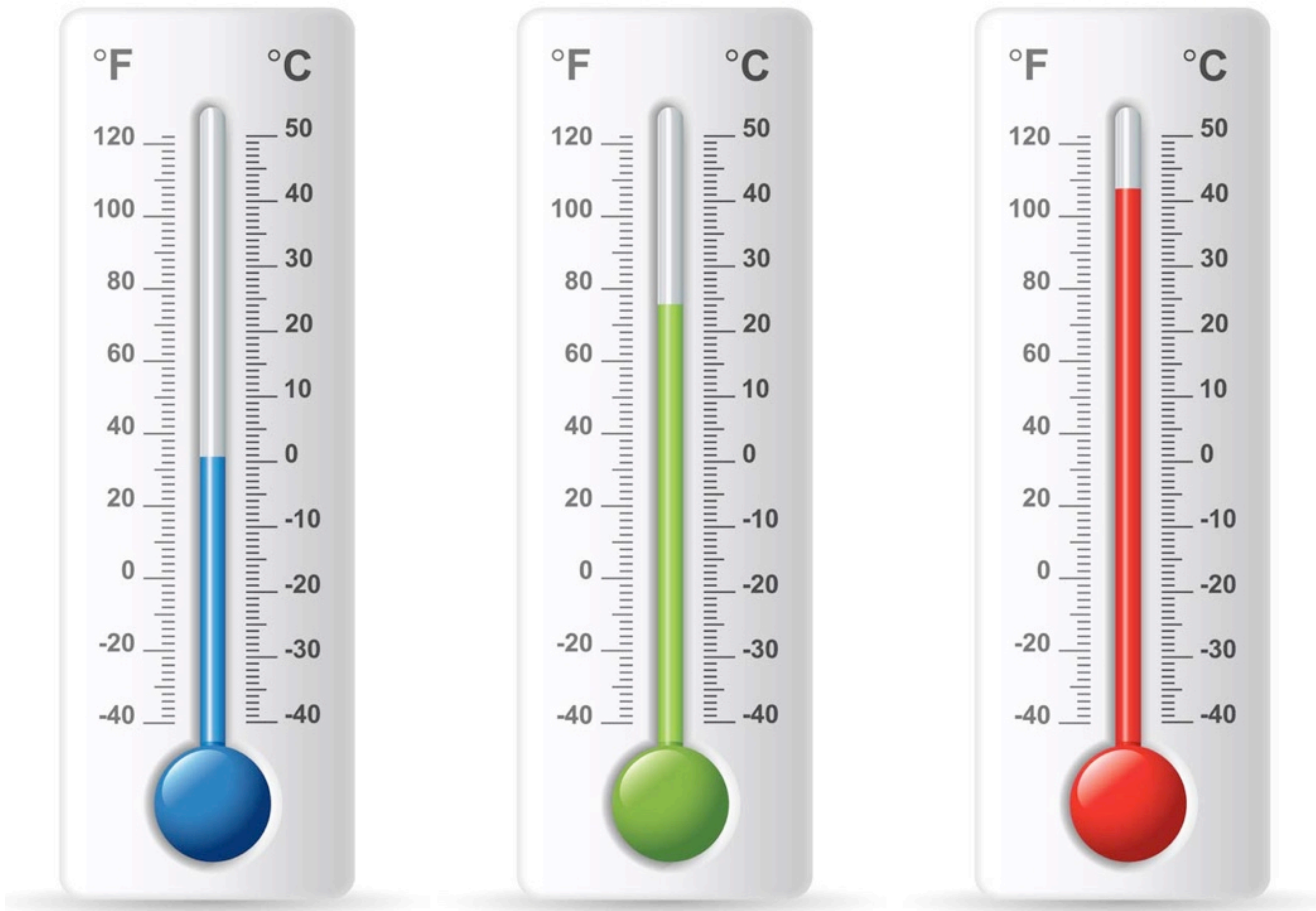
- Matter expands when you increase its temperature (contracts when temperature decreases)
- Faster-moving molecules need more room: space between adjacent molecules increases
- Decrease temperature: slower molecules can get closer together (thus occupying less volume)

Thermometers

- Thermal expansion is the basis: fill a tube with colored liquid, it will expand when heated
- Or, bond different materials together: they expand at different rates
- Or, measure the infrared coming out of your eardrum! (It would help if we knew what infrared meant)

Temperature Scales

- Relative: Scale is based on something arbitrary (like freezing/boiling of water, or human body temperature)
- Absolute: Scale references the idea of kinetic energy (lowest possible temperature occurs when all molecular motion stops)
- Fahrenheit, Celsius are relative (Rankine, Kelvin are absolute)

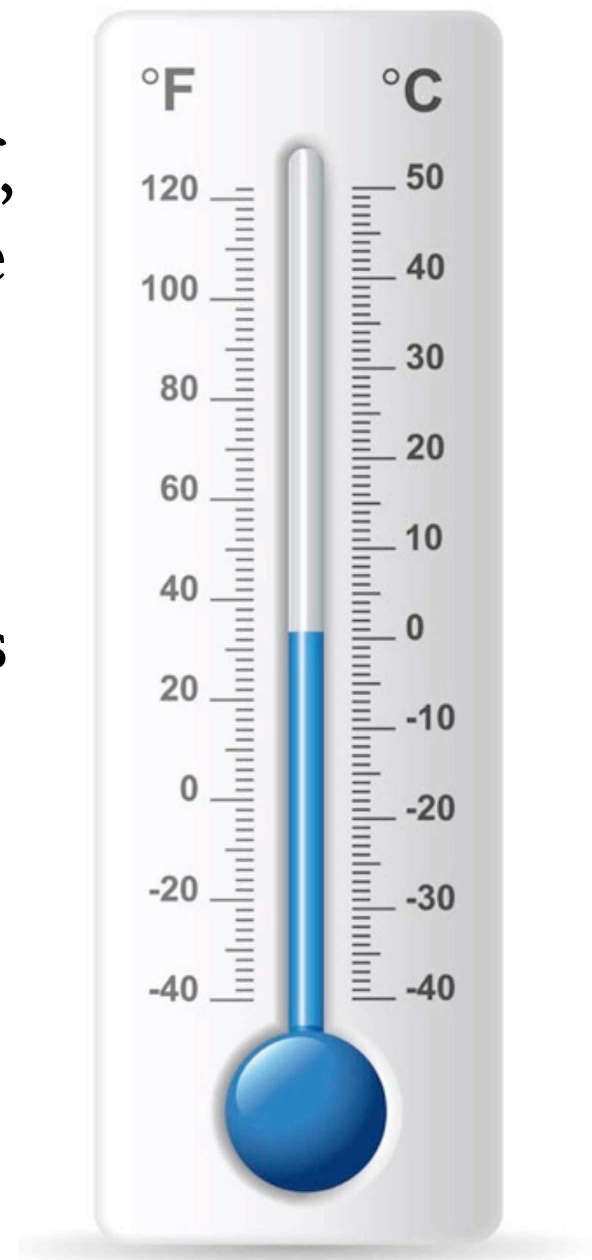


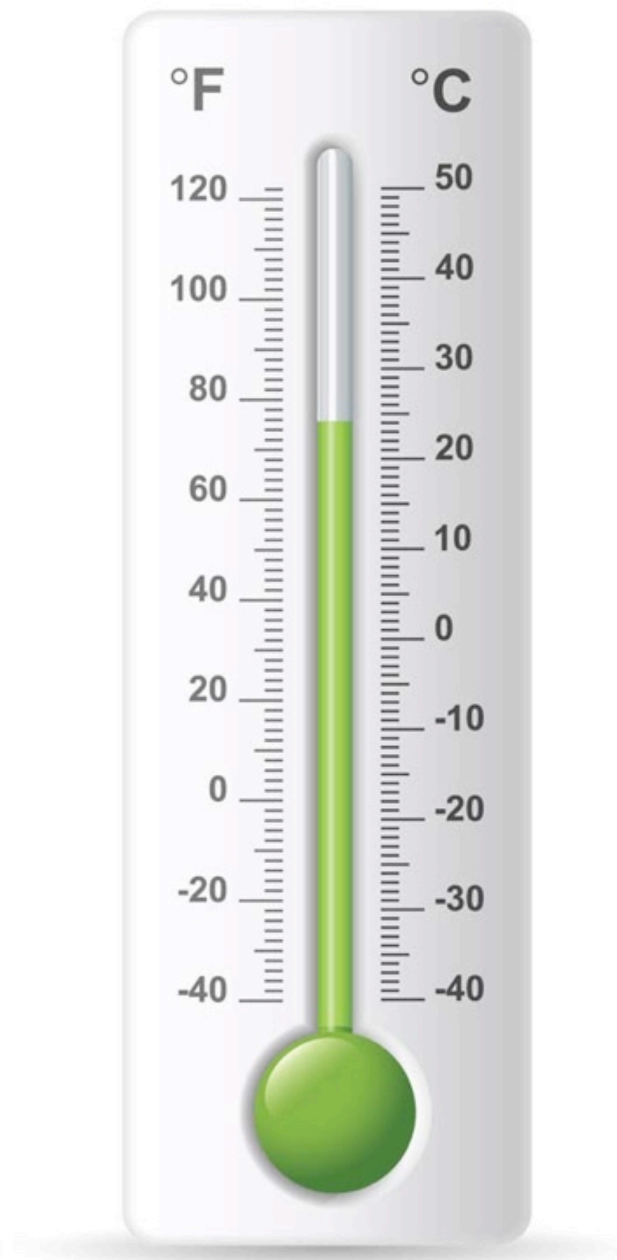
You wake up in London, and hear the radio announcer say that the high temperature for the day is expected to be in the low- to mid-20s.

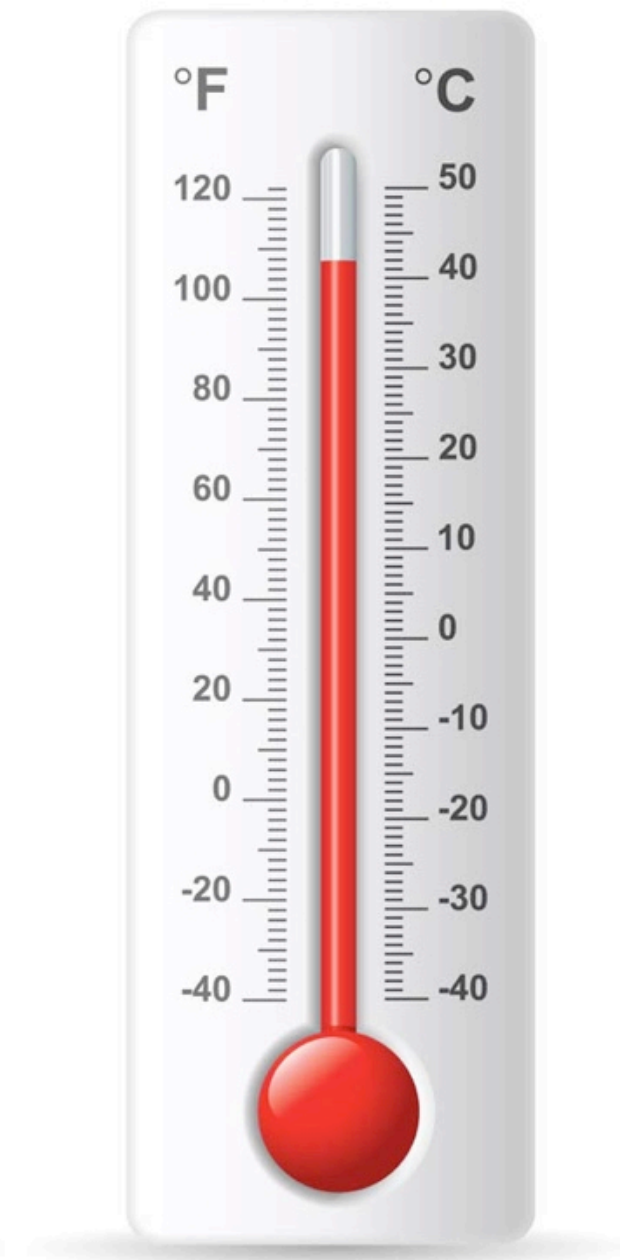
A) *Brrr!!* Better wear your parka. Hat, scarf, and mittens would be advised as well.

B) *Nice!* You will very probably be quite comfortable outdoors without a jacket.

C) *Ugh!* Absolutely sweltering. Stay inside, because that much heat will kill you in minutes.





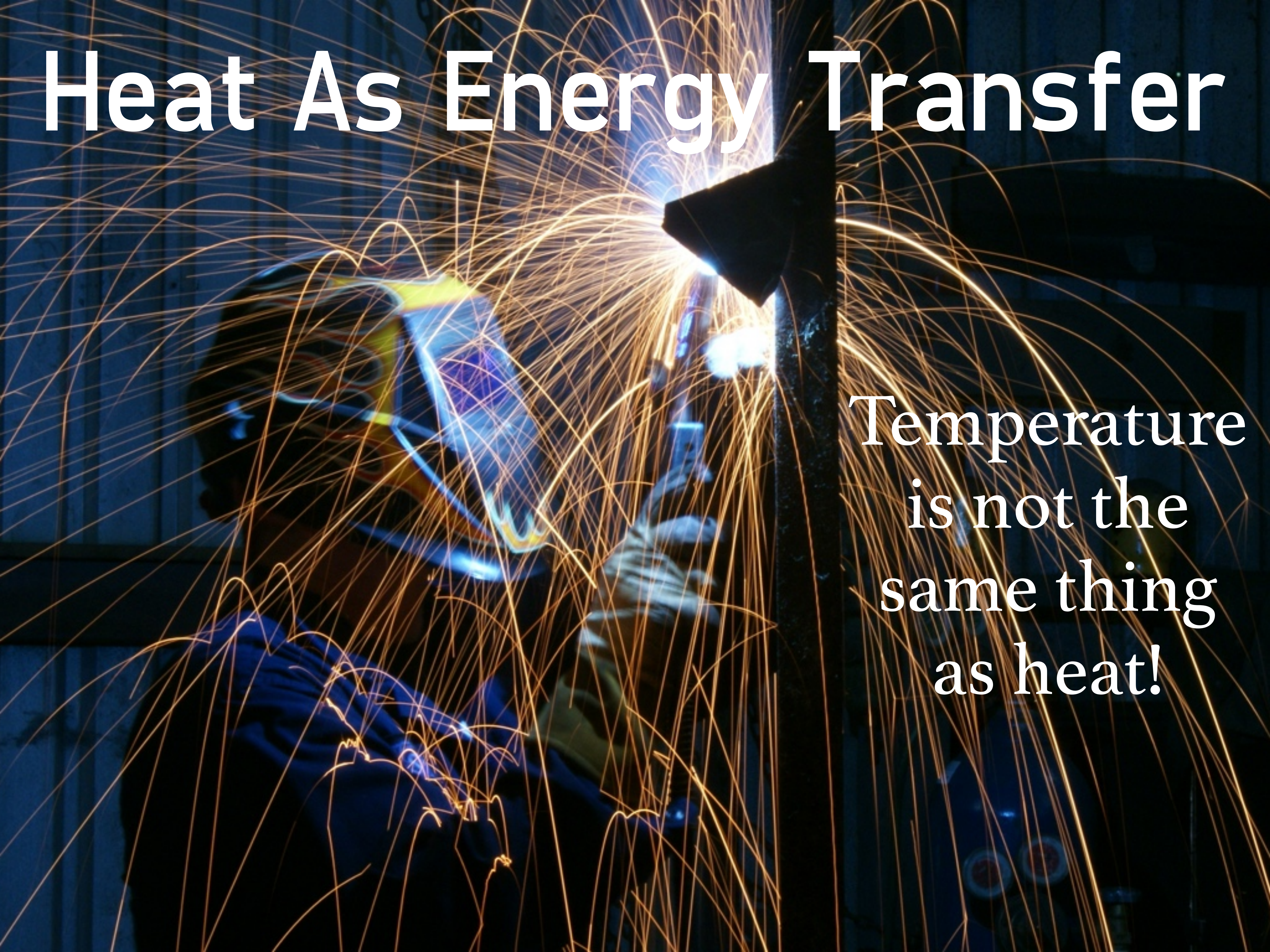


Section 4.3

Heat

Internal vs External Energy

- External: the overall KE and PE of an object
- As our ball drops from the top of the Tower of Pisa, all of its molecules are falling; the whole ball loses PE as it gains KE
- Internal: the total KE and PE of the molecules comprising the object
- As our ball drops, friction with the air causes some of its molecules to move faster, slightly increasing the temperature

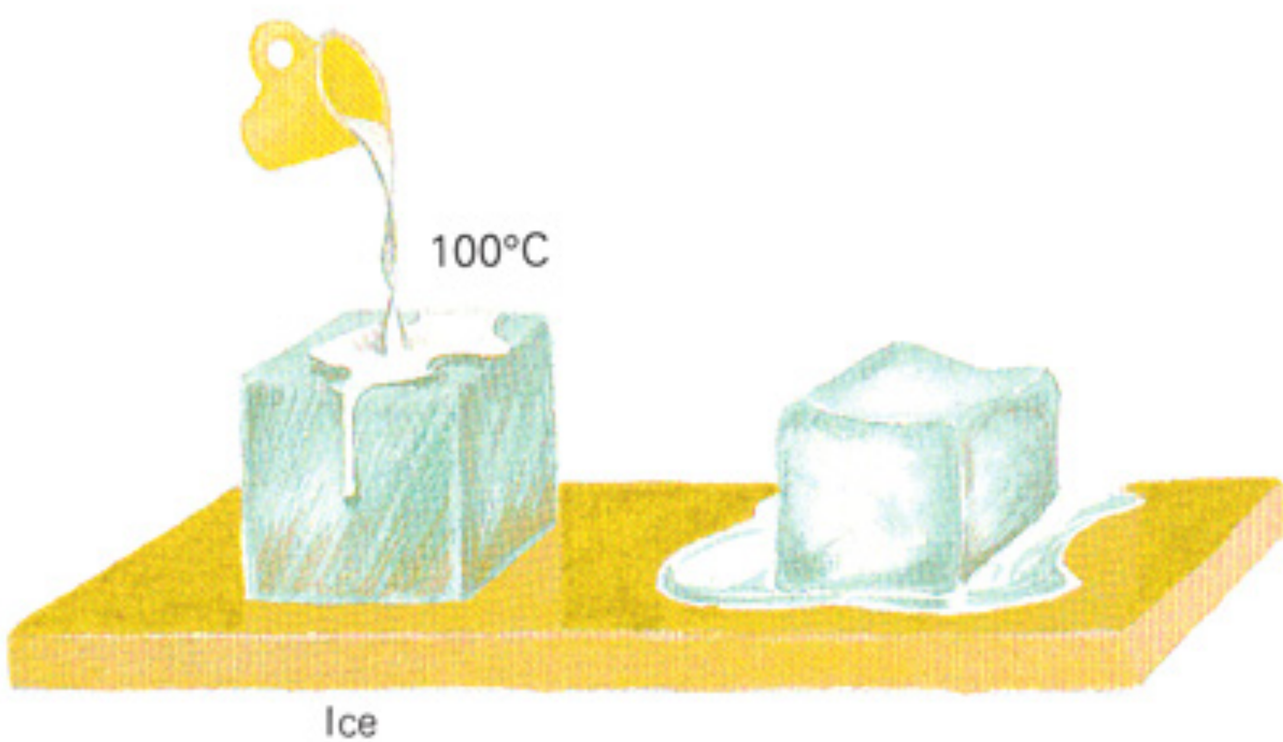

Heat As Energy Transfer
Temperature is not the same thing as heat!

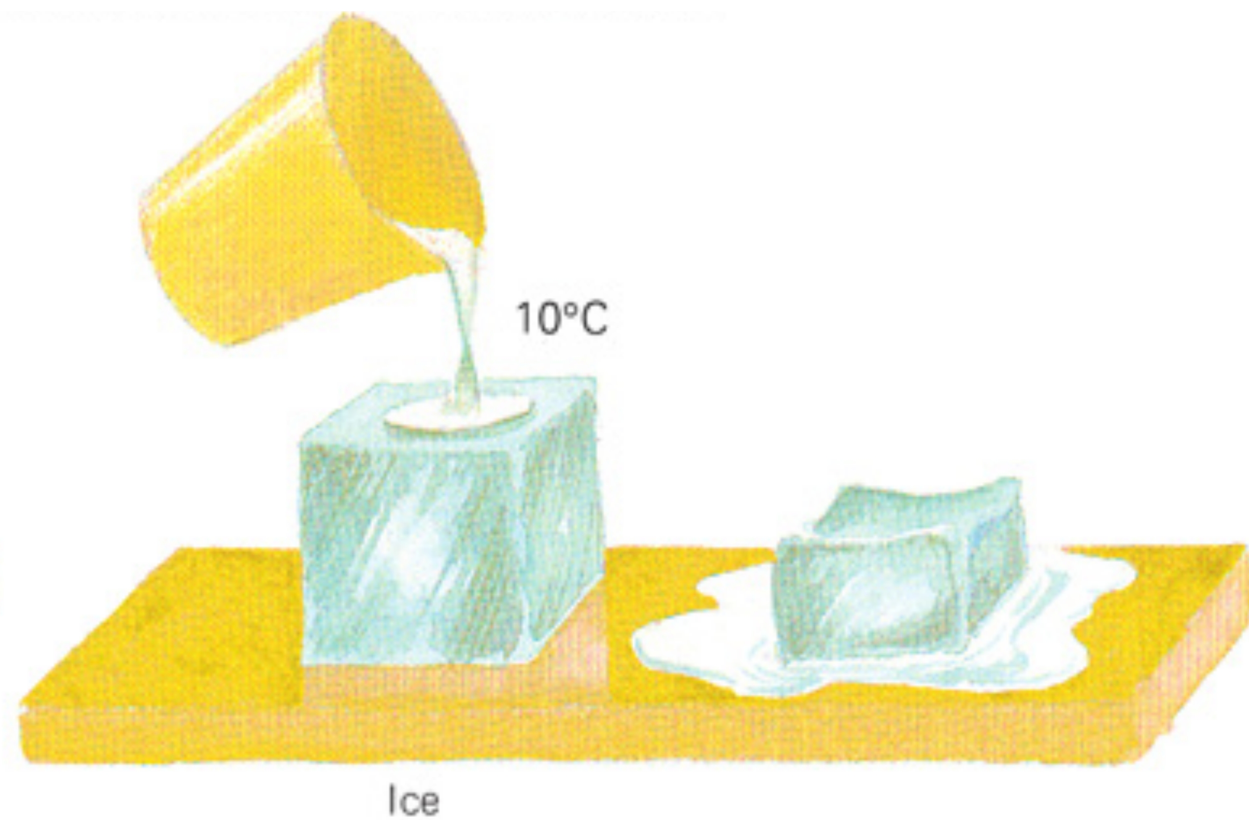

True or False:
An object might have a very high temperature, yet contain very little heat.

Heat Defined

- Definition: total internal energy absorbed or transferred from one object to another
- Energy transfer only happens in one direction: high to low (never the other direction!)
- An object with greater temperature can give energy to an object with lower temperature

Which has more heat: a 5 gallon bucket of warm water or a teacup full of boiling water?





A) Bucket

B) Teacup

C) Neither

D) No idea

Two Heating Methods

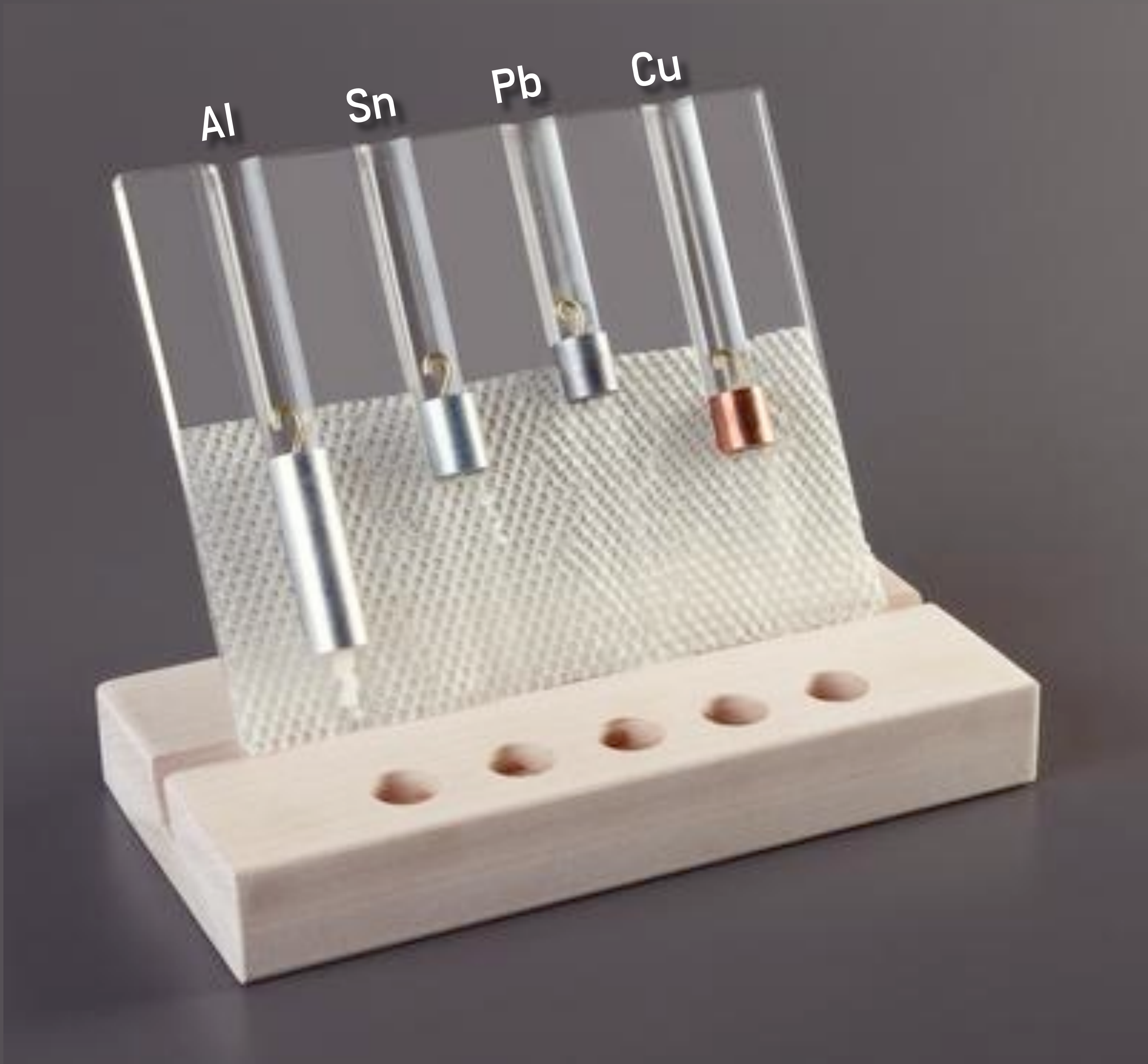
- Temperature difference: Higher energy molecule can give energy to a lower energy molecule
- Form conversion: Converting energy from one form to another always creates waste heat

Measures of Heat

- Imperial: BTU = British Thermal Unit = energy required to raise 1 lb of water by 1°F
- Metric: calorie = energy required to raise 1 g of water by 1°C
- Heat is, of course, still energy, and can be measured in Joules as well: 1 cal = 4.184 J

Specific Heat

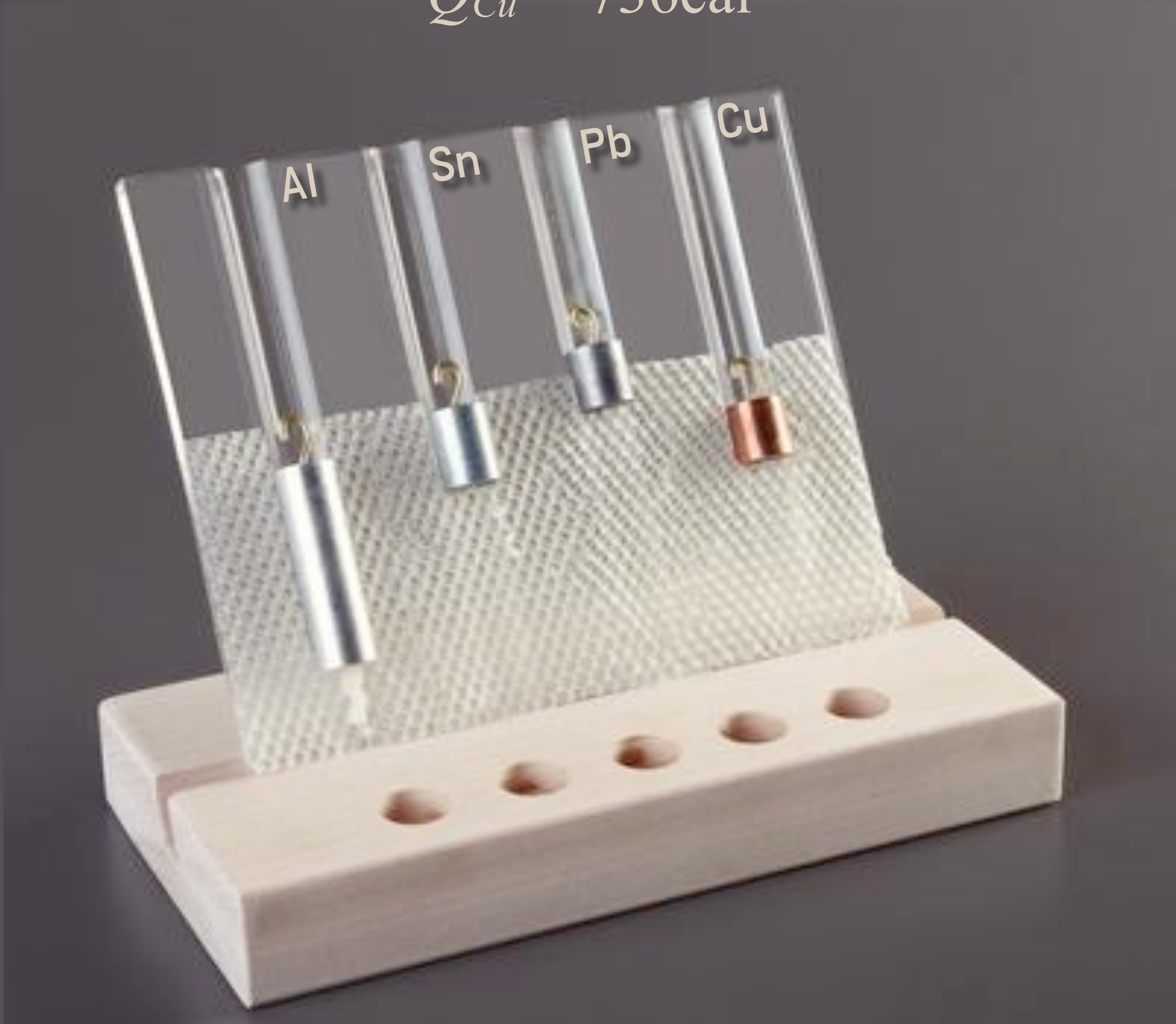
- Not everything "heats up" the same way: the material makes a difference
- Low c: iron
  $c_{FE} = 0.11\ \text{cal/g}\cdot°\text{C}$
- High c: water
  $c_{H2O} = 1\ \text{cal/g}\cdot°\text{C}$
- So, one calorie of energy raises 1g of water by 1°C, bit it raises that 1g of iron by almost 10°C!



Heat Flow

- Energy in the form of heat: $Q = mc\Delta T$
- m: The more mass you have, the more energy required to raise its temperature
- c: The higher the specific heat, the more energy you need to raise the temperature
- ΔT: The more you want to raise the temperature, the more energy you need

$$Q_{Al} = (100\text{g})(0.217\text{cal/g}\cdot{}^\circ\text{C})(100\text{-}20^\circ\text{C})$$
$$Q_{Al} = 1736\text{cal}$$
$$Q_{Sn} = (100\text{g})(0.054\text{cal/g}\cdot{}^\circ\text{C})(100\text{-}20^\circ\text{C})$$
$$Q_{Sn} = 432\text{cal}$$
$$Q_{Pb} = (100\text{g})(0.031\text{cal/g}\cdot{}^\circ\text{C})(100\text{-}20^\circ\text{C})$$
$$Q_{Pb} = 248\text{cal}$$
$$Q_{Cu} = (100\text{g})(0.092\text{cal/g}\cdot{}^\circ\text{C})(100\text{-}20^\circ\text{C})$$
$$Q_{Cu} = 736\text{cal}$$



How much heat energy would a 250-gram iron coil release as it cooled from 400°C to 20°C?

A) None.

B) -0.113 cal

C) -250 cal

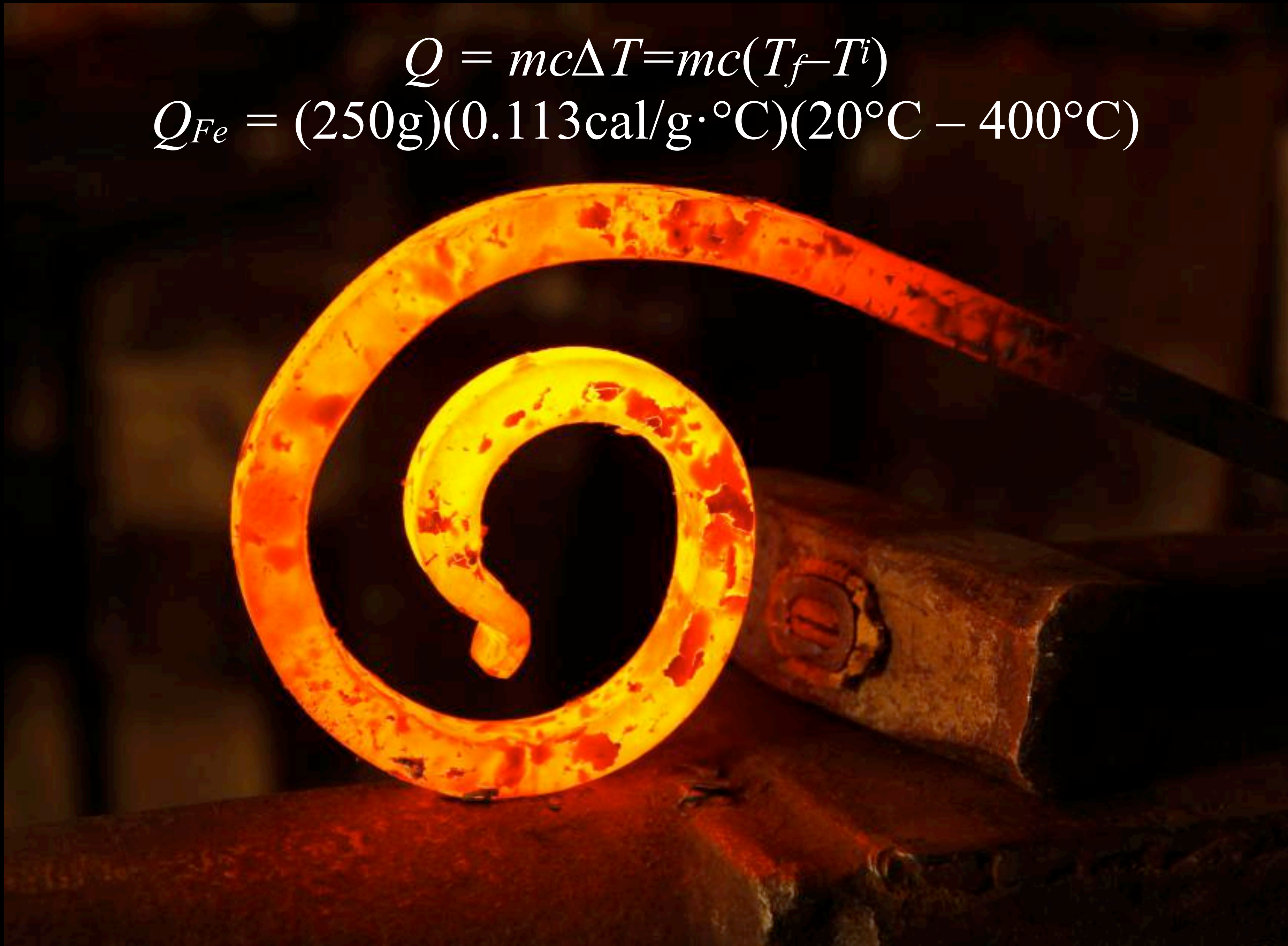
D) -400 cal

E) -10,735 cal

F) -100,000 cal

$$Q = mc\Delta T = mc(T_f - T_i)$$

$$Q_{Fe} = (250\text{g})(0.113\text{cal/g}\cdot°\text{C})(20°\text{C} - 400°\text{C})$$



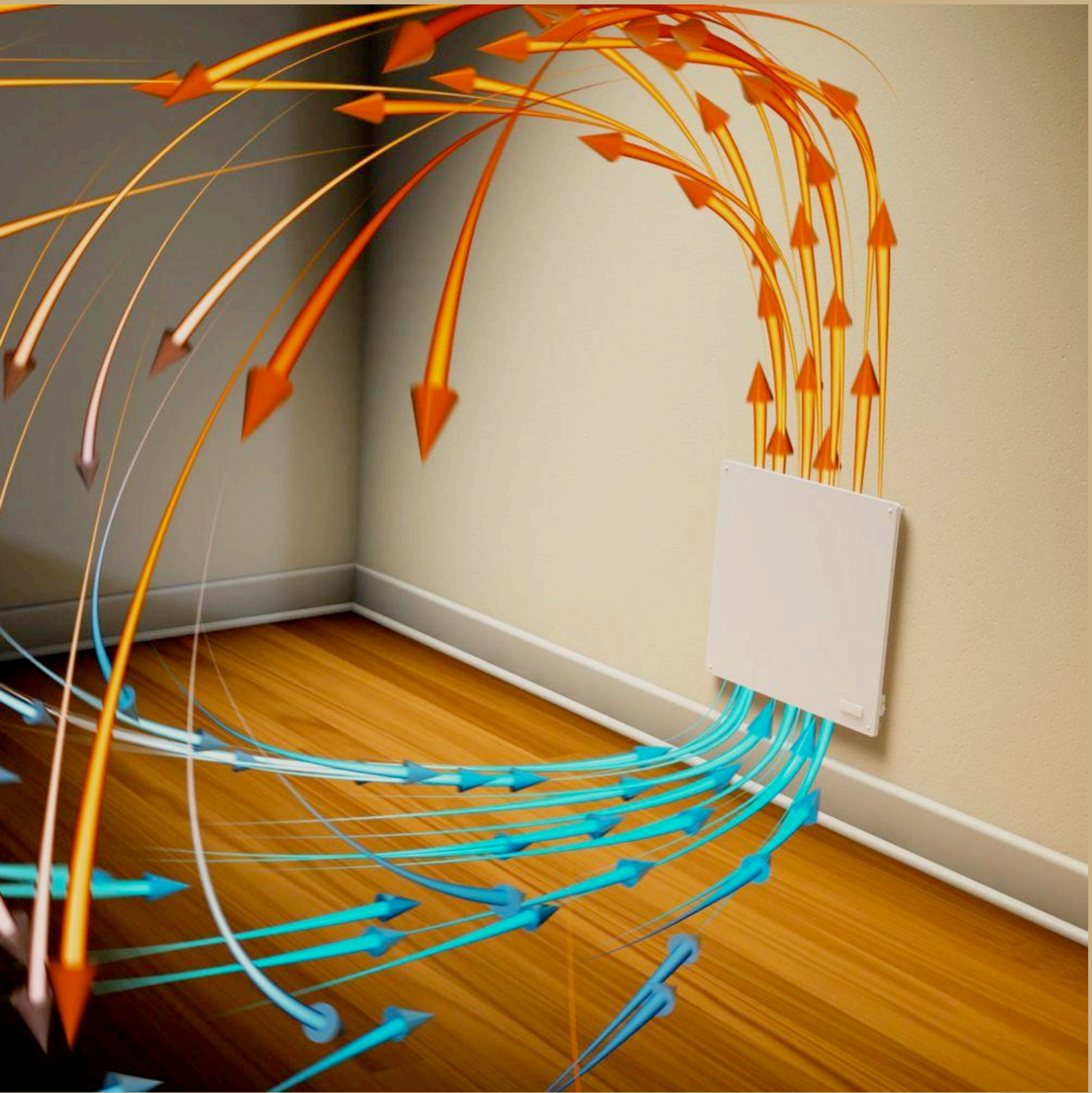
Conduction

- Heat transfer via molecular interaction: higher energy molecule gives energy to a lower energy molecule
- Requires contact
- Metallic materials are good conductors: molecules are close together, crystal structure, elasticity

True or False:

The tile feels colder to your bare feet because it has a lower temperature than the carpet.

Convection



- Energy transfer via bulk motion of the medium: move the energy by moving the whole molecule
- Only works with fluids: solids cannot do this
- Boiling water, Earth's atmosphere, surface of the sun

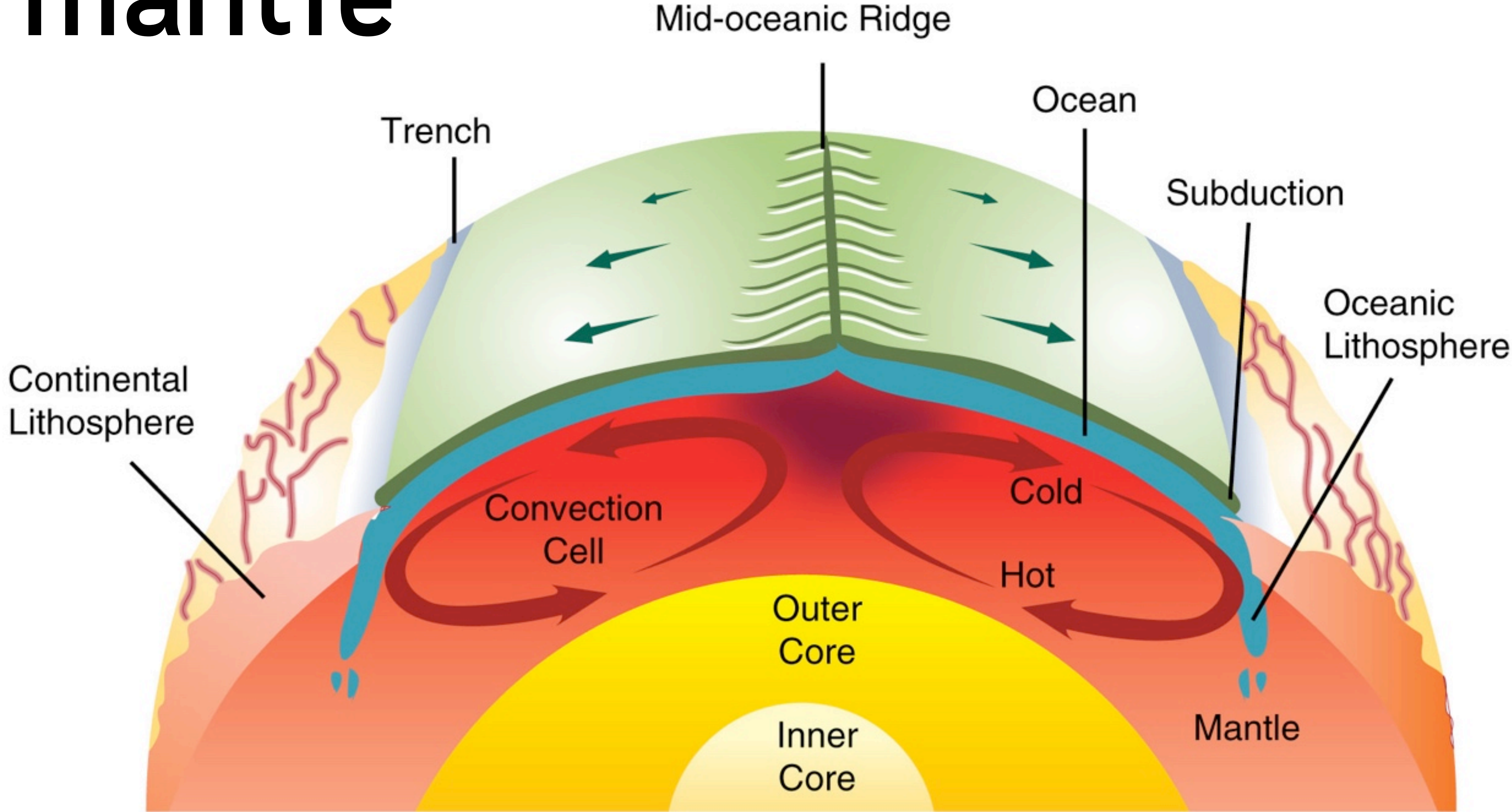
The Earth's mantle

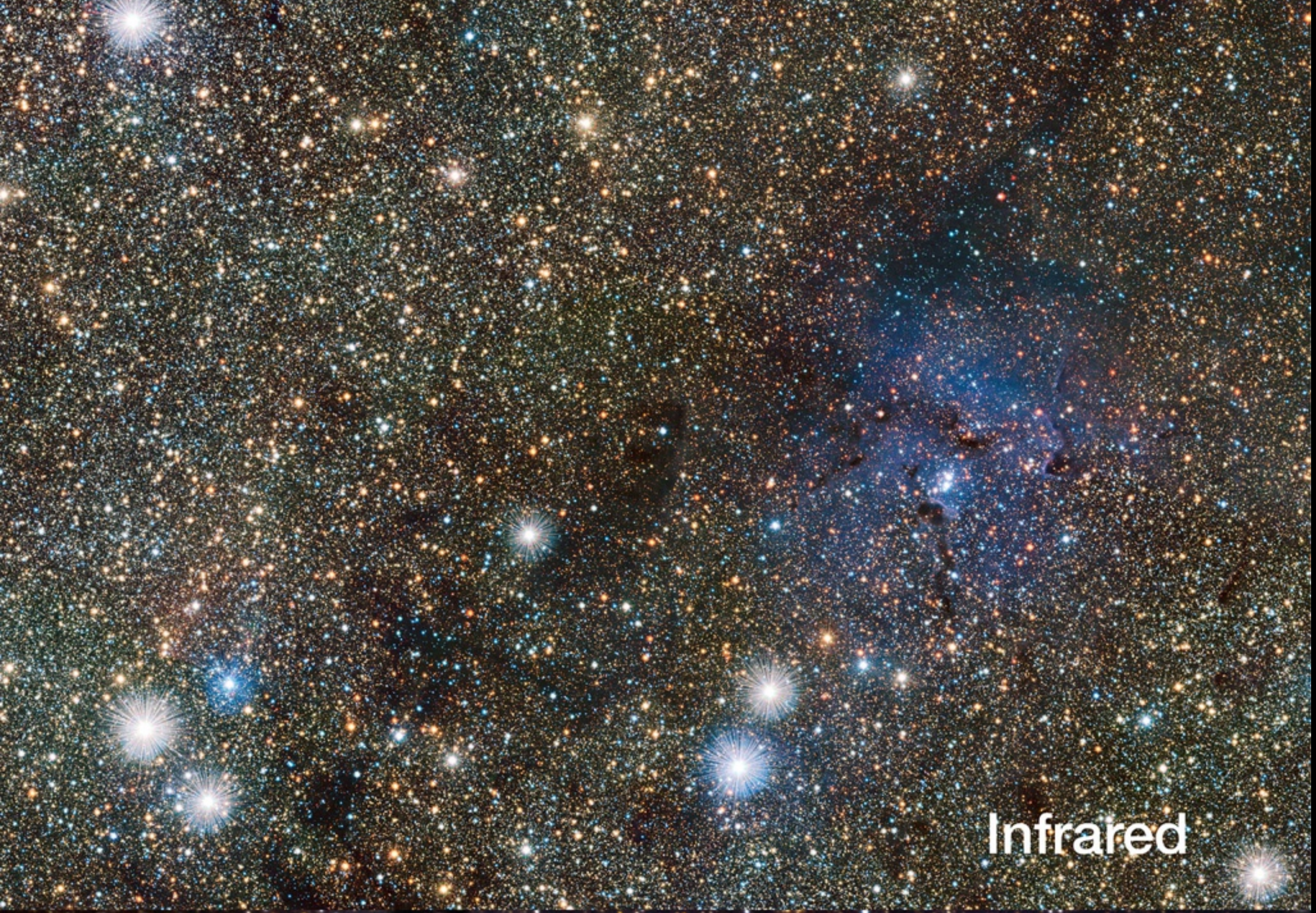
A) solid rock.

B) solid iron.

C) fluid water.

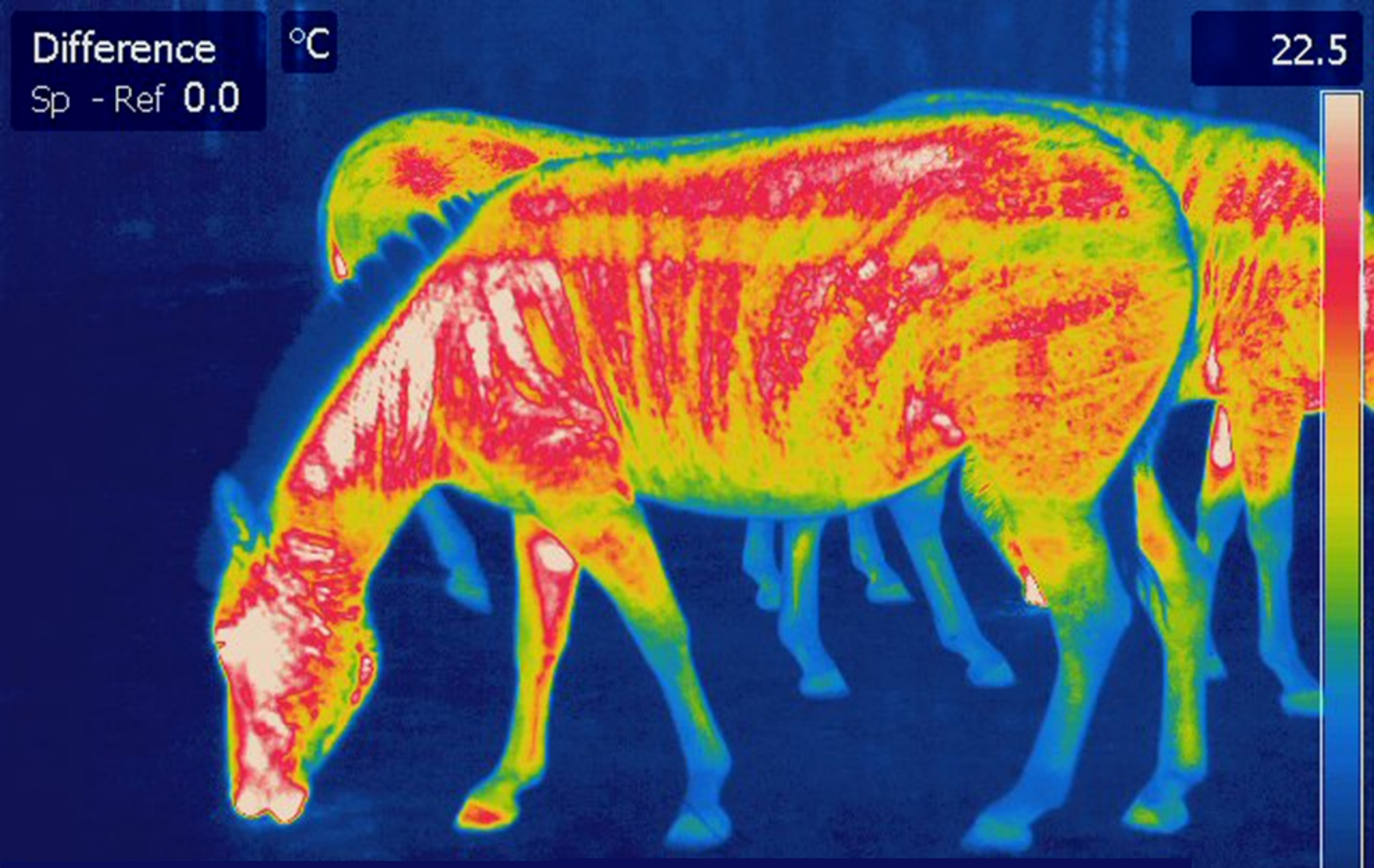
D) fluid rock.



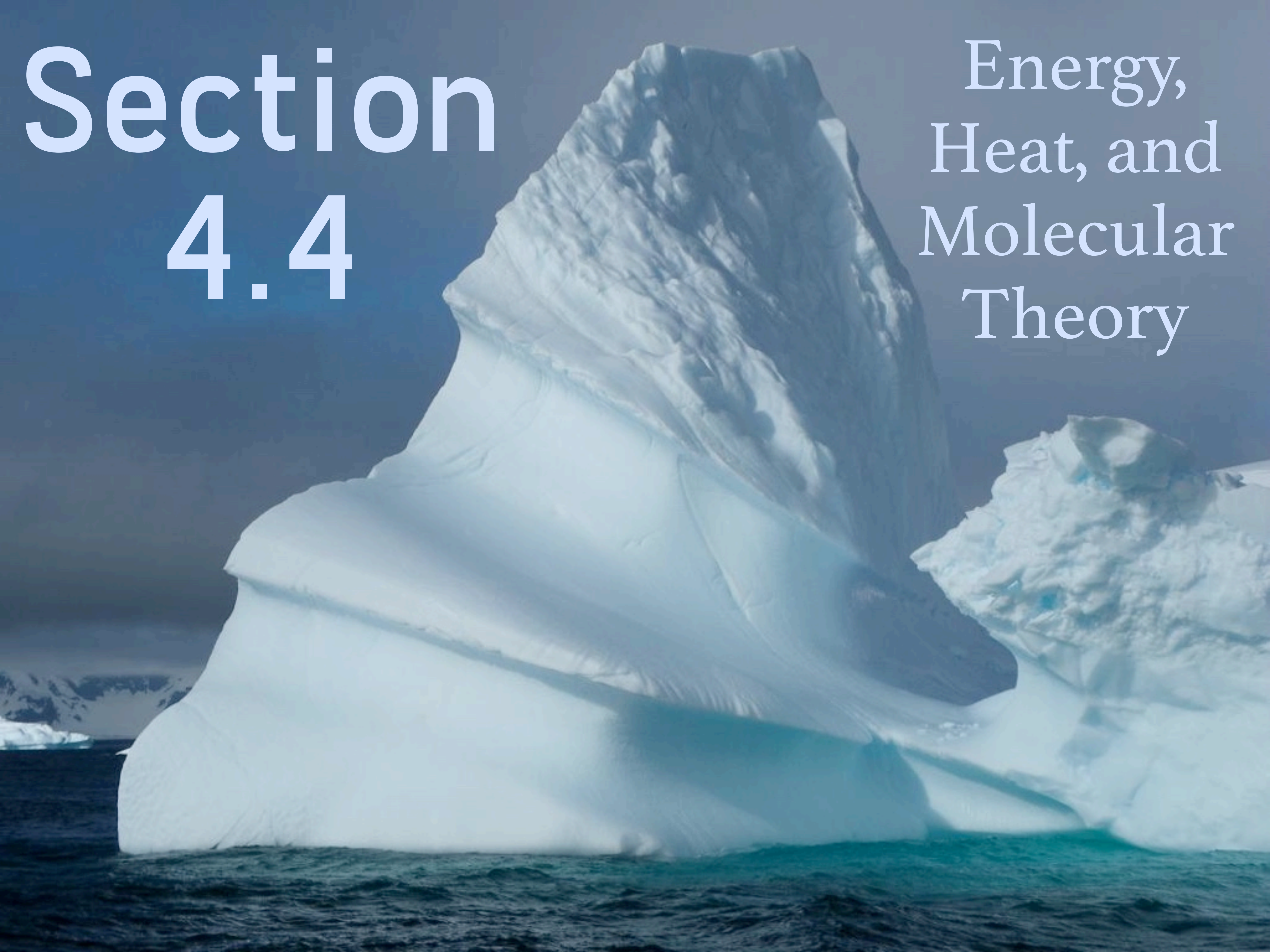


Radiation

- Energy transfer requires no material medium! Radiant energy can travel through vacuum
- Anything that is a thing has $T > 0$K, and thus radiates
- You: T about 300K, radiation = infrared
- Sun: T about 6000K, radiation = visible light

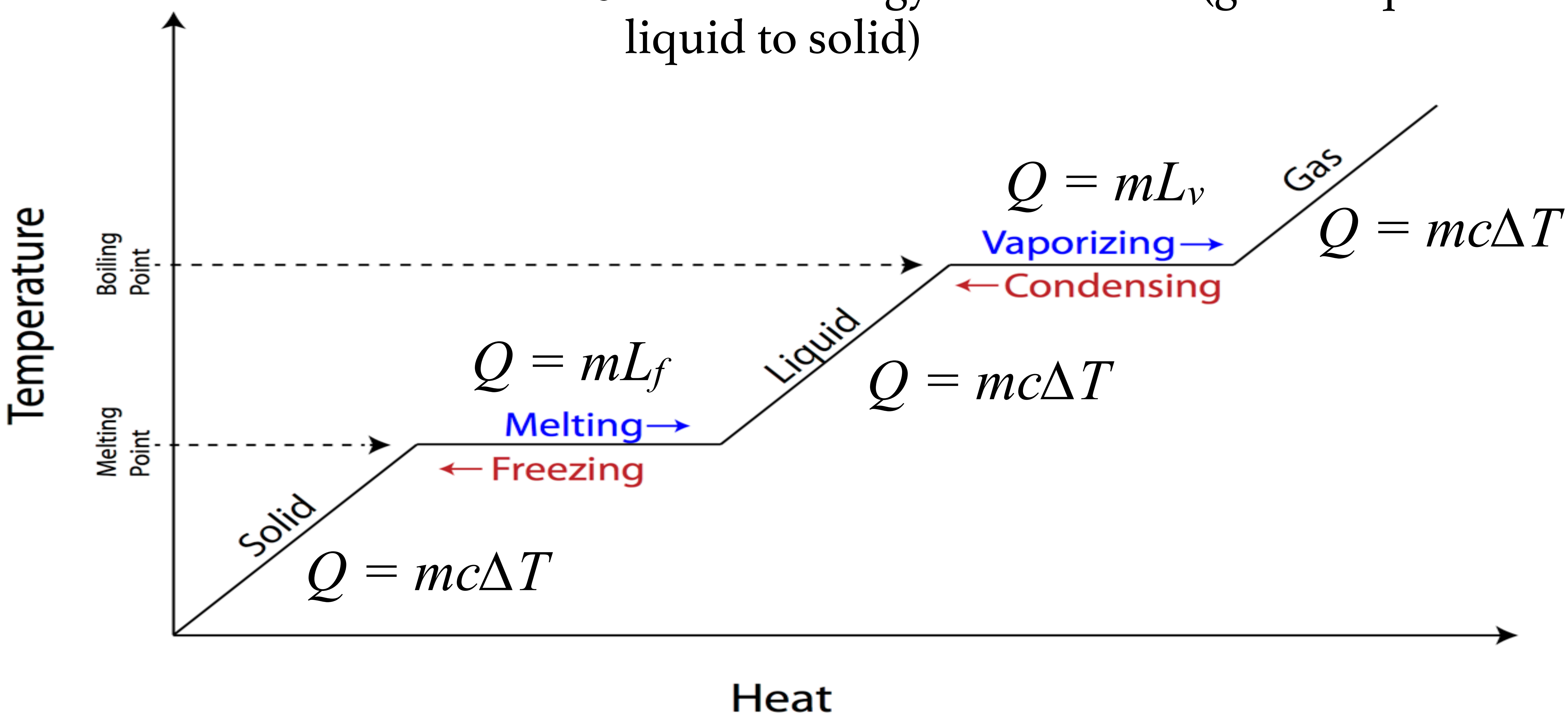


True or False: Zebra's stripes are hotter than Zebra's hooves


Section
4.4
Energy,
Heat, and
Molecular
Theory

Phase Change

- Add or subtract energy, but don't change the temperature
- Use the energy to make or break intermolecular bonds
- Absorb energy: break bonds (solid to liquid or liquid to gas)
- Release energy: form bonds (gas to liquid or liquid to solid)



True or False?

It takes the same amount of energy to raise the temperature of water by 1°C as it does to change the phase from liquid to gas (water vapor or steam).

Latent Heat of Fusion

- L_f = latent heat of fusion (either direction: solid-liquid or liquid-solid)
- Energy required to freeze/melt 1g of a substance at whatever its freezing point temperature is
- Water: $L_f = 80$ cal/g means adding 80 calories changes 1g of solid ice at 0°C into liquid water at 0°C

Calculate how much energy must be removed to freeze 100g of liquid water initially at 20°C.

Step 1: Lower the Temperature

$Q_1 = mc\Delta T$

$Q_1 = (100\text{g})(1\text{cal/g}\cdot°\text{C})(20–0)°\text{C}$

$Q_1 = 2000\text{cal}$

Step 2: Change the Phase

$Q_2 = mL_f = (100\text{g})(80\text{cal/g})$

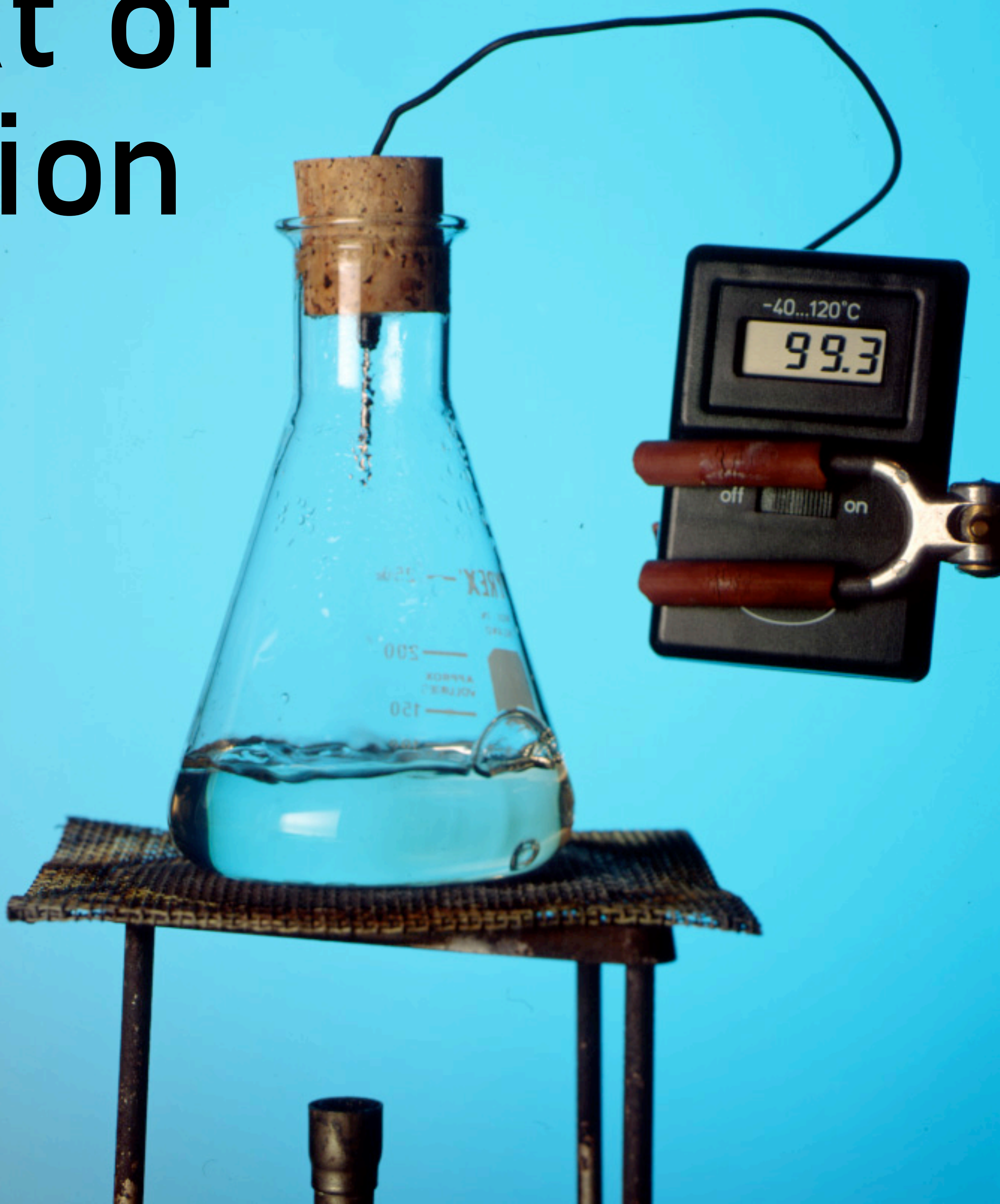
$Q_2 = 8000\text{cal}$

Step 3: Add It Up

$Q = Q_1 + Q_2 = (2000 + 8000)\text{cal}$

Latent Heat of Vaporization

- L_v = latent heat of vaporization (either direction: liquid-gas or gas-liquid)
- Energy required to boil/condense 1g of a substance at whatever its boiling point temperature is
- Water: L_v = 540 cal/g means adding 540 calories changes 1g water into steam



Calculate how much energy must be added to vaporize 100g of liquid water initially at 20°C.

Step 1: Raise the Temperature

$$Q_1 = mc\Delta T$$

$$Q_1 = (100\text{g})(1\text{cal/g}\cdot{}^\circ\text{C})(100-20^\circ\text{C})$$

$$Q_1 = 8000\text{cal}$$

Step 2: Change the Phase

$$Q_2 = mL_v = (100\text{g})(540\text{cal/g})$$

$$Q_2 = 54000\text{cal}$$

Step 3: Add It Up

$$Q = Q_1 + Q_2 = (8000+54000)\text{cal}$$

Evaporation

- Not quite the same as boiling!
- Average energy means some molecules have more energy than others–possibly much more
- Highest energy molecules can escape, leaving lower energy molecules behind
- Overall average can be significantly less than the boiling point of the liquid

Condensation

- Not quite the same thing as melting!
- Bathroom mirror is cooler than the steam from the shower
- Higher energy water molecules give energy to the lower energy molecules of the mirror
- The water molecules (now stuck to the mirror) have lower energy, and return to the liquid phase

Evaporation Rate

- Increase the overall temperature, increase the rate of evaporation
- More surface area exposed, greater rate of evaporation
- Lower humidity (or a breeze!), faster evaporation
- Reduce air pressure for quicker evaporation